

ERDC/CHL TR-04-11

Coastal and Hydraulics Laboratory



**US Army Corps  
of Engineers®**  
Engineer Research and  
Development Center

*Monitoring Completed Navigation Projects Program*

## **Inspections of Previously Monitored Rubble-Mound Coastal Structures**

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Glenn B. Myrick

September 2004

20041129 001

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Final report

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**ABSTRACT:**

This report presents results of inspections of rubble-mound coastal structures monitored previously under the Monitoring Completed Navigation Projects (MCNP) Program. Expedient, low-cost walking inspections were performed at 11 sites. Positions of breakwater and jetty armor units were compared with their positions in previous aerial photography and photogrammetric surveys. Settlement of portions of the structures as well as voids in their armor cover also was noted, and photographs of the structures were obtained. Summaries of inspection results as well as recommendations are presented in this report. The work was conducted under the "Periodic Inspections" work unit of the MCNP Program.

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# Contents

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Conversion Factors Non-SI to SI Units of Measurement.....	vi
Preface .....	vii
1—Introduction .....	1
Monitoring Completed Navigation Projects Program .....	1
Objective of Periodic Inspections Work Unit .....	2
Study Scope .....	3
2—Project Descriptions and Inspection Results .....	5
St. Paul Harbor Breakwater, AK.....	5
Yaquina Bay North Jetty, OR .....	8
Siuslaw River Jetties, OR .....	11
Umpqua River Training Jetty, OR.....	14
Crescent City Harbor Breakwater, CA .....	16
Humboldt Bay Jetties, CA .....	18
Burns Harbor Breakwater, IN .....	20
Cleveland Harbor East Breakwater, OH.....	24
Cattaraugus Creek Harbor Breakwater, NY .....	28
Manasquan Inlet Jetties, NJ .....	30
Ocean City Inlet South Jetty, MD.....	34
3—Summary and Recommendations .....	38
References .....	42
SF 298	

## List of Figures

---

Figure 1.	Approximate locations of coastal sites visited .....	4
Figure 2.	Layout of St. Paul Harbor, AK.....	6
Figure 3.	View of St. Paul Harbor main breakwater.....	7
Figure 4.	Layout of Yaquina Bay jetties.....	8

Figure 5.	Head of Yaquina Bay north jetty on 24 June 1997 .....	10
Figure 6.	Voids on seaward side of Yaquina north jetty .....	10
Figure 7.	Void on channel side of Yaquina north jetty.....	11
Figure 8.	Layout of Siuslaw River jetties and spurs .....	12
Figure 9.	Photo shows loss of elevation at tip of Siuslaw north jetty head .....	13
Figure 10.	Area on shoreward side of Siuslaw south jetty spur head where steep slope exists .....	13
Figure 11.	Layout of Umpqua River jetties .....	15
Figure 12.	View of Umpqua River training jetty (looking shoreward).....	15
Figure 13.	Breach at head of Umpqua south jetty .....	16
Figure 14.	Layout of Crescent City Harbor, CA.....	17
Figure 15.	View of Crescent City breakwater .....	18
Figure 16.	Layout of Humboldt Bay jetties, CA.....	19
Figure 17.	Outer end of Humboldt Bay north jetty .....	20
Figure 18.	Close-up view of 38,100-kg (42-ton) dolosse armor cover .....	20
Figure 19.	Layout of Burns Harbor, IN .....	21
Figure 20.	View of Burns Harbor breakwater in 1999 (looking east) .....	23
Figure 21.	View of Burns Harbor Breakwater in 2004 (looking west) .....	24
Figure 22.	Steep slope on harbor side of Burns Harbor breakwater .....	24
Figure 23.	Layout of Cleveland Harbor, OH.....	25
Figure 24.	View of 1,814-kg (2-ton) dolosse along trunk of Cleveland Harbor east breakwater .....	27
Figure 25.	View of 3,628-kg (4-ton) dolosse at head of Cleveland Harbor east breakwater.....	27
Figure 26.	Void area on lakeside of Cleveland East Breakwater between stas 230+40 and 230+70 .....	28
Figure 27.	Layout of Cattaraugus Creek Harbor breakwaters, NY .....	29
Figure 28.	Cattaraugus Creek south breakwater looking lakeward .....	30

Figure 29.	Void and steep slope at head of Cattaraugus Creek south breakwater .....	30
Figure 30.	Layout of Manasquan Inlet jetties, NY .....	31
Figure 31.	View of Manasquan Inlet north jetty .....	33
Figure 32.	View of a 17,235-kg (19-ton) Core-Loc armor unit placed on Manasquan Inlet jetties .....	33
Figure 33.	Layout of Ocean City Inlet structures, MD, after 1985 rehabilitation.....	35
Figure 34.	View of inner portion (to sta 13+00) of rehabilitated Ocean City Inlet south jetty trunk .....	36
Figure 35.	Headland breakwaters at Ocean City Inlet constructed to stabilize shoreline .....	36
Figure 36.	Seaward portion of south jetty at Ocean City Inlet (beyond sta 13+00) after 2002 rehabilitation .....	37

# Conversion Factors, Non-SI to SI Units of Measurement

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Non-SI units of measurement used in figures, plates, and tables of this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4046.85736	square meters
cubic yards	0.76465549	cubic meters
degrees (angle)	0.01745329	radians
feet	30.48	centimeters
feet	0.3048	meters
inches	0.0254	meters
inches	2.54	centimeters
miles (u.s. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
square miles	2.59	square kilometers
tons (2,000 pounds, mass)	907.1847	kilograms

# Preface

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The study reported herein was conducted as part of the Monitoring Completed Navigation Projects (MCNP) Program, formerly Monitoring Completed Coastal Projects Program. Work was carried out under Work Unit 11M-7, "Periodic Inspections." Overall program management for MCNP is administered by Headquarters, U.S. Army Corps of Engineers (HQUSACE). The Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), is responsible for technical as well as data management and support for HQUSACE review and technology transfer. Technical Monitors for the MCNP Program are Messrs. Barry W. Holliday, Charles B. Chesnutt, and David B. Wingerd, HQUSACE. The Program Manager is Robert R. Bottin, Jr., CHL.

This report presents results of inspections of rubble-mound coastal structures that have been previously monitored under the MCNP Program. The information contained in this report was obtained by walking inspections of the structures by Messrs. Bottin, Glenn B. Myrick, and Larry R. Tolliver, CHL.

The work was conducted during the period May 2003 through June 2004 under the general supervision of Mr. Thomas W. Richardson and Dr. William D. Martin, Director and Deputy Director, CHL, and under the direct supervision of Mr. Dennis G. Markle, Chief, Harbors, Entrances and Structures Branch. This report was prepared by Messrs. Bottin, Tolliver, and Myrick.

Dr. James R. Houston was Director of ERDC. COL James R. Rowan, EN, was Commander and Executive Director.



# 1 Introduction

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## Monitoring Completed Navigation Projects Program

The goal of the Monitoring Completed Navigation Projects (MCNP) Program (formerly the Monitoring Completed Coastal Projects Program) is the advancement of coastal and hydraulic engineering technology. The program is designed to determine how well projects are functioning relative to design requirements and weathering attacks of their physical environment. These determinations, combined with concepts and understandings already available, are leading to development of more accurate and economical engineering solutions to coastal and hydraulic problems; to strengthened and improved design criteria and methodology; to improved construction practices and cost-effectiveness; and to improved operation and maintenance techniques. Additionally, the monitoring program is identifying where current technology is inadequate or where additional research is required.

To develop the direction for the program, the U.S. Army Corps of Engineers initially established an ad hoc committee of engineers and scientists. The committee formulated the objectives of the program, developed its operational philosophy, recommended funding levels, and established criteria and procedures for project selection. A significant result of their efforts was a prioritized listing of problem areas to be addressed, essentially a listing of the areas of interests for the program.

Corps offices are invited to nominate projects for inclusion in the monitoring program as funds become available. The MCNP Program is governed by Engineer Regulation 1110-2-8151 (Headquarters, U.S. Army Corps of Engineers (HQUSACE) 1997). A selection committee reviews and prioritizes the projects nominated based on criteria established in the regulation. The prioritized list is reviewed by the technical monitors at HQUSACE. Final selection is based on this prioritized list, national priorities, and the availability of funds.

The overall monitoring program is under the management of the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), with guidance from HQUSACE. Development of monitoring plans and conduct of data collection and analyses are dependent upon the combined resources of CHL and the various Districts/Divisions.

The coastal structures inspections for the study reported herein, were completed as part of the "Periodic Inspections" work unit of the MCNP Program.

## **Objective of Periodic Inspections Work Unit**

The objective of the "Periodic Inspections" work unit in the MCNP Program is to periodically monitor selected coastal navigation structures to gain an understanding of the long-term structural response of unique structures to their environment. These periodic data sets are used to improve knowledge in design, construction, and maintenance of both existing and proposed future coastal navigation projects. These data also will help avoid repeating past design mistakes that have resulted in structure failure and/or high maintenance costs. Past projects monitored under the MCNP Program, and/or structures with unique design features that may have application at other sites, are considered for inclusion in the periodic inspections monitoring program. Selected sites are presented as candidates for development of a periodic inspection monitoring plan. Once the monitoring plan for a site is approved and funds are provided, site monitoring is initiated. Normally, base conditions are established and documented in the initial effort. The site then is reinspected on a periodic basis (frequency of surveys is based on a balance of need and funding for each monitoring site) to obtain long-term structural response data.

Relatively low-cost remote sensing tools and techniques, with limited ground truthing surveys, are the primary inspection tools used in the monitoring efforts. Most periodic inspections consist of capturing above-water conditions of the structure at periodic intervals using high-resolution aerial photography. Periodic aerial photographs are compared visually to gauge the degree of in-depth analysis required to quantify structural changes (primarily armor unit movement). Data analysis involves using photogrammetric techniques developed for and successfully applied at other coastal sites. At sites where local wave data are being gathered by other projects and/or agencies, and these data can be acquired at a relatively low cost, wave data are correlated with structural changes. In areas where these data are not available, general observations and/or documentation of major storms occurring in the locality are presented along with the monitoring data if available. Ground surveys are generally limited to the level needed to establish the accuracy of the photogrammetric techniques.

When a coastal structure is photographed at low tide, an accurate permanent record of all visible armor units is obtained. Through the use of stereoscopic, photogrammetric instruments in conjunction with photographs, details of structure geometry can be defined at a point in time. By direct comparison of photographs taken at different times, as well as the photogrammetric data resolved from each set of photographs, geometric changes (i.e., armor unit movement and/or breakage) of the structure can be defined as a function of time. Thus, periodic inspections of the structures will capture permanent data that can be compared and analyzed to determine if structure changes are occurring that indicate possible failure modes and the need to monitor the structure(s) more closely.

It was requested in the Field Review Group Meetings/Program Reviews that structures monitored during past MCNP efforts be revisited periodically to determine how they are performing in their environments. These were to be expedient, low-cost, walking inspections, and would be performed under the "Periodic Inspections" work unit of the MCNP Program. Initial inspections were conducted during the period June 1997 through September 1998 (Bottin and Tolliver 1999). Inspections reported herein occurred between May 2003 and June 2004.

## Study Scope

The rubble-mound coastal structures visited during the conduct of this study included those monitored under the MCNP Program since its inception (1980s) through 2000. Eleven rubble-mound coastal structures were visited, and their approximate locations are shown in Figure 1. Numbers in the figure correspond to the sites shown in the following tabulation.

Number	Coastal Site
1	St. Paul Harbor breakwater, AK
2	Yaquina Bay north jetty, OR
3	Siuslaw River jetties, OR
4	Umpqua River training jetty, OR
5	Crescent City Harbor breakwater, CA
6	Humboldt Bay jetties, CA
7	Burns Harbor breakwater, IN
8	Cleveland Harbor east breakwater, OH
9	Cattaraugus Creek Harbor breakwater, NY
10	Manasquan Inlet jetties, NJ
11	Ocean City Inlet south jetty, MD

Inspections and assessments of the coastal structures at the various sites did not include the use of instrumentation. Rather, walking inspections and/or boat surveys were conducted, and general notes were made comparing armor unit positions during the inspections versus their positions in previous aerial photography. Settlement of portions of the structures as well as voids in their armor also were noted and photographs of the structures were obtained. In some instances, District personnel accompanied CHL personnel during the assessments. These procedures were considered adequate to obtain expedient, low-cost information required relative to the structures' condition.

Additional rubble-mound coastal structures are periodically inspected, but are not included in this report, since they were recently monitored through detailed, photogrammetric analyses. Included are coastal structures at Kahului Harbor, HI, and Laupahoe Point Boat Launching Facility, HI (Bottin and Meyers 2002a); Nawiliwili Harbor, HI (Bottin and Meyers 2002b); and Ofu Harbor, American Samoa (Bottin and Meyers 2003).

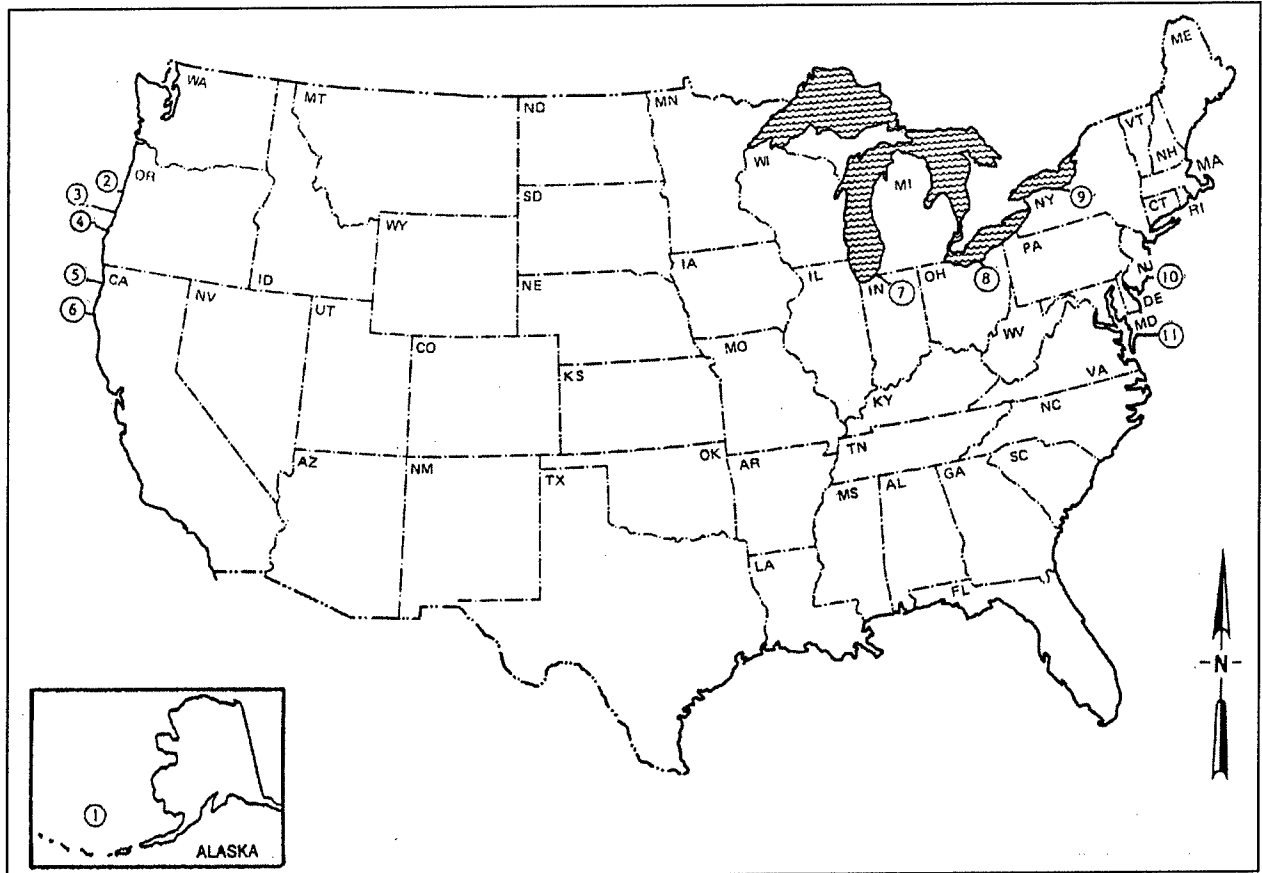


Figure 1. Approximate locations of coastal sites visited

## 2 Project Descriptions and Inspection Results

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### St. Paul Harbor Breakwater, AK

St. Paul Harbor is located in a cove on the southern tip of St. Paul Island, the northernmost and largest island of the Pribilofs, in the eastern Bering Sea. A breakwater was originally constructed at St. Paul in 1984, but failed during storms that year. A new structure was designed and constructed in 1987. It was 229 m (750 ft)<sup>1</sup> in length and functioned well with regard to stability, but was not of sufficient length to provide wave protection to vessels during storm events.

In 1989, the current harbor configuration was completed. It consisted of a 549-m-long (1,800-ft-long) main breakwater and a 296-m-long (970-ft-long) detached structure (Figure 2). Armor stone used on the main breakwater trunk was 16,329 kg (18 tons), and 21,772-kg (24-ton) armor was used on the head. The slope of the trunk was 1V:2H, with a 1V:3H slope around the breakwater head. The detached structure was armored with 4,536-kg (5-ton) stone with a slope of 1V:1.5H. Model investigations were used to develop the breakwater layout (Bottin and Mize 1988) and ensure breakwater stability (Ward 1988).

St. Paul Harbor was originally monitored during the period July 1993 through June 1996 (Bottin and Eisses 1997). The objective was to determine if the harbor and its structures were performing (both functionally and structurally) as predicted by model studies used in the project design. Monitoring included prototype wave gauging, wave hindcast studies, wave runup, wave overtopping, and bathymetric analyses, as well as broken armor unit surveys and photogrammetric analyses of the 320-m-long (1,050-ft-long) main breakwater extension. The initial photogrammetric survey of 1994 revealed low areas along much of the breakwater. Breakwater topography indicated that only about 5 percent of the structure was at its design elevation (el). About 66 percent was within 0.6 m (2 ft) of its design el and 29 percent of the structure length was 0.6 m (2 ft) below its design el. The survey revealed 73 broken/cracked armor stones above the waterline. An additional photogrammetric survey in 1996 revealed very slight change in breakwater el relative to the initial 1994 survey. Generally, there was no change in the crown el of the structure, except for a few

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<sup>1</sup> Units of measurement in the text of this report are shown in SI units, followed by non-SI units in parenthesis. In addition, a table of factors for converting non-SI units of measurement used in figures in this report to SI units is presented on page vi.

localized areas. A broken armor unit survey revealed 230 broken/cracked armor stones above the water level on the main breakwater.

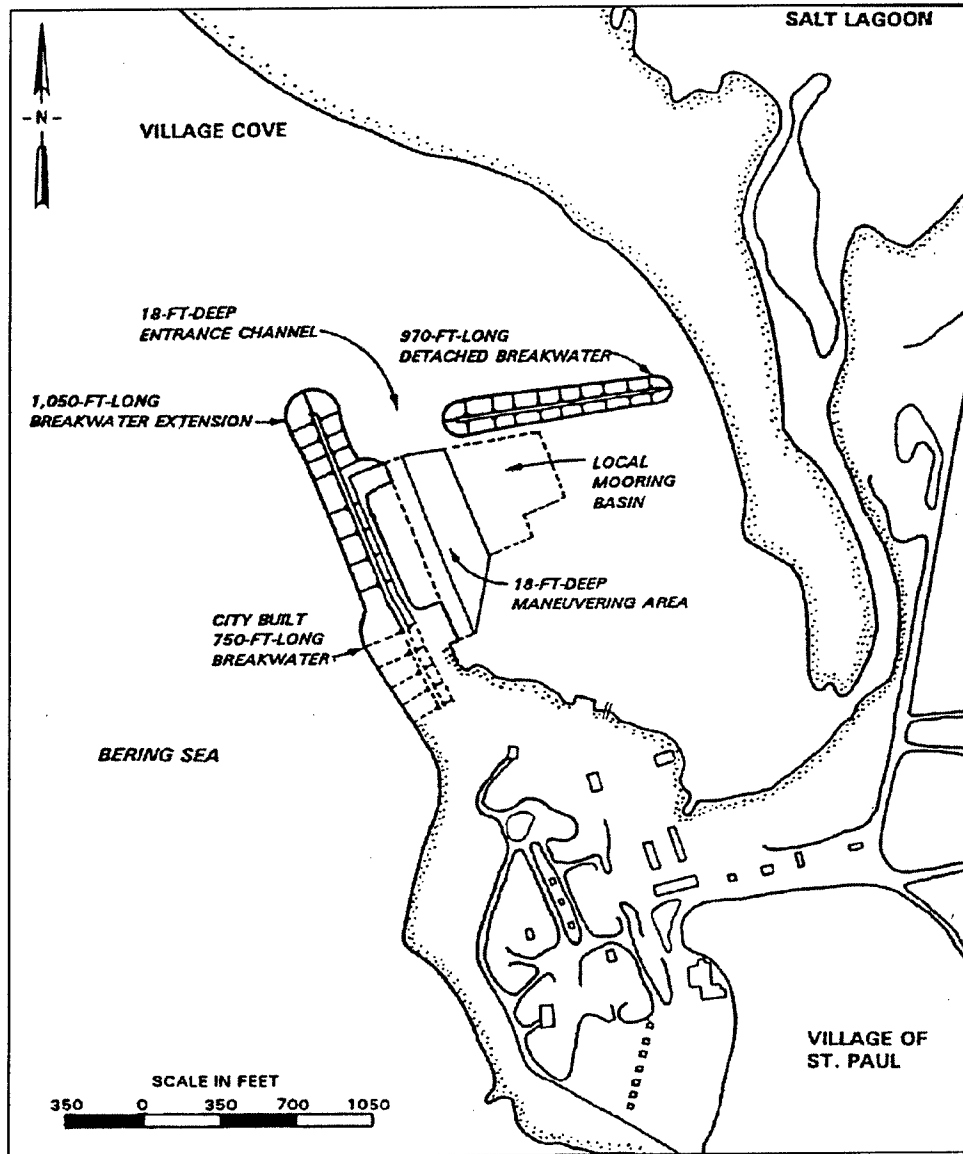


Figure 2. Layout of St. Paul Harbor, AK

The breakwater was again monitored in 2000 through limited ground surveys, aerial photography, photogrammetric analysis, and a broken armor unit survey as part of the “Periodic Inspections” work unit of the MCNP Program (Bottin and Jeffries 2001). In general, topography indicated that very little change had occurred in the crest elevation of the breakwater since 1996. Voids and/or subsistence (on the order of 1.5 m (5 ft)) had occurred in localized areas. A broken armor unit survey revealed 221 broken or cracked armor stones above the waterline. Twenty four new broken stones were noted since the 1996 survey, and 33 broken stones documented during the previous inspection could not be found. They could have been removed by wave and/or ice action. An obvious void observed during the broken armor unit survey was in a stretch along the waterline

on the sea-side slope between sta 8+80 and 9+70 where core stone was exposed in one area.

To minimize further breakwater damage and reduce overtopping of the main breakwater, the construction of three submerged reef breakwaters seaward of the structure was completed during the 2001 construction season. In addition, the void area between sta 8+80 and 9+70 was repaired. The 2000 periodic inspection of the breakwater extension not only determined changes in the armor unit field since previous studies, but established new base conditions since construction of the reef breakwaters. Reef breakwater design was tested and optimized in a model study (Bottin 1996).

The most recent walking inspection of the St. Paul Harbor main breakwater (Figure 3) was conducted on 17 June 2003. Although isolated subsidence and voids were noted in areas of the breakwater, comparisons with the latest breakwater topography confirmed that these areas existed in 2000. The inspection indicated little visual change in the structure el. However, further deterioration of some of the broken/cracked armor stones was observed. Overall the breakwater was in good condition. Seaward of the breakwater, it was noted that kelp had attached to the reef breakwaters and was growing vertically almost to the water surface.



Figure 3. View of St. Paul Harbor main breakwater

## Yaquina Bay North Jetty, OR

Yaquina Bay is a tidal estuary located on the Oregon coast approximately 177 km (110 miles) south of the Washington state line. The present navigation project consists of a navigation channel maintained to a depth of -12.2 m (-40 ft) mean lower low water (mllw) at the entrance and protected by two parallel rubble-mound breakwaters which are separated by a distance of about 305 m (1,000 ft). A layout of the project is illustrated in Figure 4.

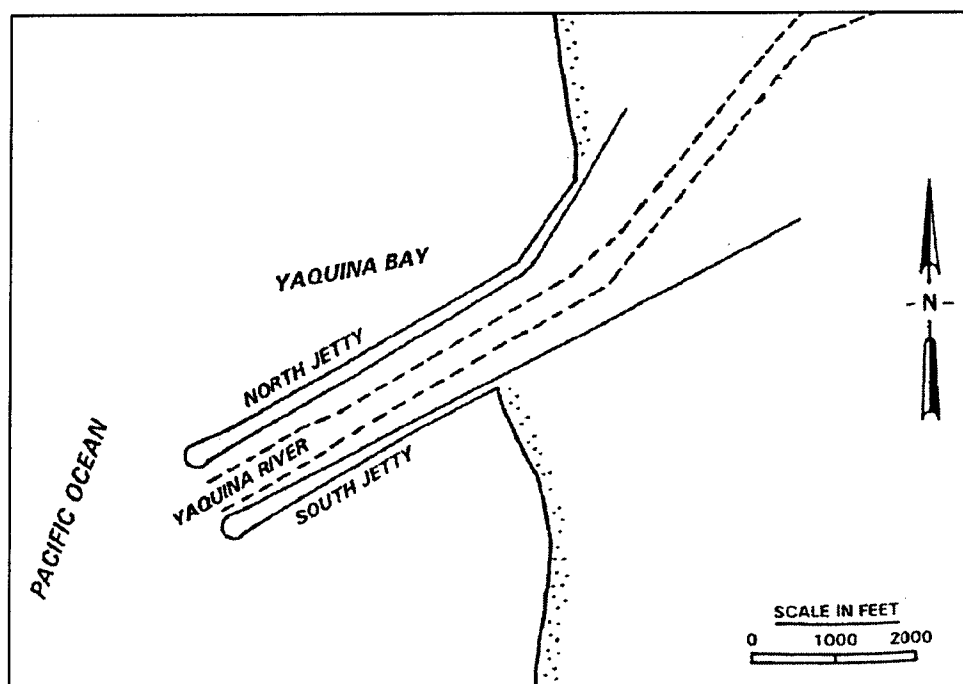


Figure 4. Layout of Yaquina Bay jetties

Since initial authorization of the Federal navigation project, more than 100 years ago, the two jetties protecting the entrance channel have undergone a series of extensions and repairs. The south jetty has been extended three times to its present authorized length of 2,620 m (8,600 ft), and the north jetty also has undergone three extensions to reach its present authorized length of 2,240 m (7,350 ft). Since its final extension in 1972, no additional repair work has been required on the south jetty; however, the north jetty has required two rehabilitations since its final extension in 1966 and 1988. In both instances, severe wave conditions reduced the seawardmost 137 m (450 ft) of the structure to elevations below the water level, posing a hazard to navigation and creating increased dredging requirements. During the 1988 repair, the seawardmost 30.5 m (100 ft) of the jetty was armored with 29,485-kg (32.5-ton) stone. The next 30.5-m (100-ft) repair length was armored with 23,405-kg (25.8-ton) stone, and the landwardmost portion of the rehabilitation was armored with 16,330-kg (18-ton) stone. The crest was 9.1 m (30 ft) in width and had an el of +6.1 m (20 ft). Side slopes were 1V:2H. A model study was used to study stability (Grace and Dubose 1988) of the 1988 rehabilitation.



The troublesome history of the Yaquina Bay north jetty, coupled with some of the harshest wave conditions on the west coast of the United States, prompted the monitoring study. The jetty was monitored during the period October 1988 through September 1994 (Hughes et al. 1995). The objectives of the monitoring study were to (a) determine what mechanisms were responsible for damage that occurred at the Yaquina Bay north jetty, (b) use the study information to improve Corps design and construction capabilities for similar harsh environments, and (c) obtain information for use in the design of a permanent repair of the north jetty. At the conclusion of the monitoring, a notch, or void region, was clearly visible on the sea side of the jetty approximately 30.5 m (100 ft) shoreward of the tip. In addition, it was apparent that stones also were missing from the sea side of the jetty tip.

An inspection of the north jetty on 24 June 1997 revealed that the head of the structure no longer existed. Comparisons to photogrammetric data obtained in May 1993, indicated that approximately 50 m (165 ft) of the north jetty head was no longer above water, and stone had apparently been removed by wave action to down below the water level. When the notch area was not visible, measurements from known locations on the structure were made to confirm this finding. Remnants of some of the jetty could be seen seaward of the structure in wave troughs as they passed. Above-water stone slopes around the head were not uniform (Figure 5). Other observations of the structure revealed some low areas in the crest and some voids on the sea side of the jetty. At a location approximately 305 m (1,000 ft) shoreward of the jetty head (the head location of 24 June 1997), low areas in the crest existed over about a 30.5-m (100-ft) span. Another low area was observed on the crest about 520 m (1,700 ft) shoreward of the current jetty head, and a void on the sea side of the jetty was observed approximately 580 m (1,900 ft) from the current jetty head. An even larger void on the sea side of the structure was observed about 650 m (2,125 ft) shoreward of the jetty head. There were additional sporadic areas along the structure crest that could use armor stones to bring the jetty back to its design cross section.

Subsequent to the 1997 inspection, the head of the north jetty was again rehabilitated. It was capped with 34,475-kg (38-ton) stone on a 1V:2.5H slope above the waterline. A two-layer (6.9-m-wide (22.5-ft-wide)) toe berm consisting of 26,310-kg (29-ton) stone was placed from the waterline to the ocean bottom to buttress the main body of the jetty head. The crest width of the head was increased from 9.1 to 12.2 m (30 to 40 ft). The repair section extended from sta 68+00 to 70+00. Construction was completed in September 2001.

The most recent walking inspection of the Yaquina north jetty was conducted on 27 August 03. The head of the jetty was in excellent condition. The trunk of the structure was similar to that observed in 1997. Subsidence was observed in areas along the crest on the seaward portion of the jetty. Voids observed previously (Figures 6 and 7) appeared to be similar in appearance, and there were other sporadic areas along the crest that could use armor stone to bring the jetty back to its design cross section. Overall, the structure was in good condition.



Figure 5. Head of Yaquina Bay north jetty on 24 June 1997

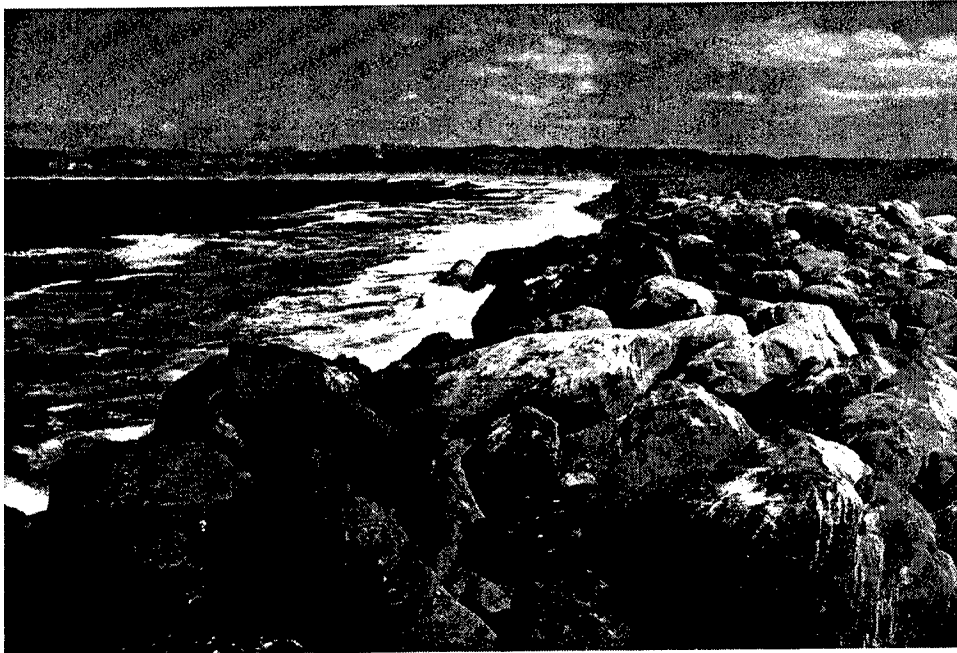


Figure 6. Voids on seaward side of Yaquina north jetty



Figure 7. Void on channel side of Yaquina north jetty

## Siuslaw River Jetties, OR

The Siuslaw River is approximately 174 km (108 miles) long and enters the Pacific Ocean south of the city of Florence, OR, about 250 km (155 miles) south of the Washington state border. Improvements for navigation at Siuslaw River began before the turn of the century with the start of a jetty system by local interests. Federal participation in the project began in 1910 and consisted of two entrance jetties and a navigation channel extending upriver. The north jetty was originally 2,957 m (9,700 ft) long, and the south jetty was 1,980 m (6,500 ft) in length. Jetty construction was completed in 1917. Other improvements were subsequently authorized, one of which provided for extending the jetties to the -6.1-m (-20-ft) mllw depth. In 1985, the jetties at the mouth of the Siuslaw River were again extended seaward. The north jetty extension was 580 m (1,900 ft) long, and the south jetty extension was 670 m (2,200 ft). In addition, on the ocean sides of each jetty, 122-m-long (400-ft-long) spurs oriented 45 deg to the main structure were constructed. The spurs originated 275 m (900 ft) shoreward of the jetty heads. The jetty heads were located in depths of about -7 m (-23 ft) mllw. Figure 8 shows a layout of the Siuslaw River jetties and spurs which were developed in a model study (Bottin 1981). The jetty extensions and spurs were of randomly-placed rubble-mound construction using armor stone ranging from 10,885-to 17,235-kg (12- to 19-ton).

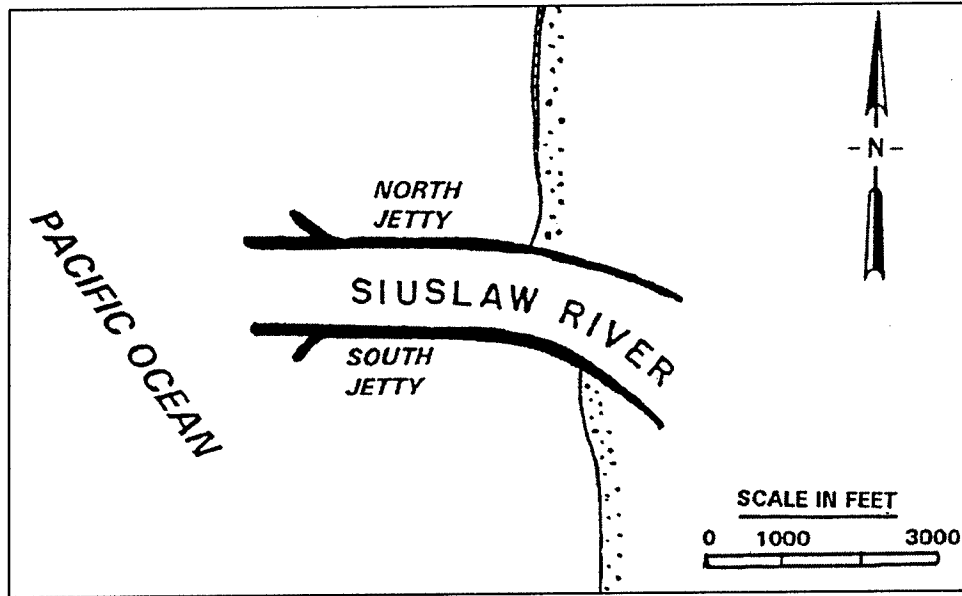


Figure 8. Layout of Siuslaw River jetties and spurs

The jetty extensions and spurs were monitored during the period September 1988 through September 1993 (Pollock et al. 1995). The objectives of the monitoring program were to (a) determine if the spurs effectively deflected sediment, (b) identify shoaling patterns near the jetties, (c) compare prototype conditions against those predicted by a physical model study, (d) evaluate the effectiveness of the system in reducing maintenance dredging requirements, and (e) evaluate the impact of the jetties on the surrounding beaches.

An inspection of the jetty system on 26 June 1997 revealed that some repairs were needed. On the north jetty head, a void was observed on the channel side of the structure. The area was steep, and it appeared stone had been pulled downslope by wave action as remnants could be seen seaward of the area. About 20 m (65 ft) shoreward of the jetty head, a low area existed in the center of the crest, and approximately 27.5 m (90 ft) from the head a void existed on the channel side of the structure. In several areas along the jetty extension, it appeared that the center portion of the crest had subsided and the elevation was irregular. The stone along the slopes, however, appeared to be up to required elevation. At a point out about half the length of the jetty spur, it appeared a stone had been uplifted leaving a small void. With the exception of the jetty head, the slopes on the north jetty extension and jetty spur were in good condition. Inspection of the south jetty extension indicated a similar situation at the sea side of the jetty head. The slope was steep, and it appeared that stones had been pulled downslope by wave action. The head of the south jetty spur also was damaged on its shoreward side as evidenced by a lack of stone above the water surface. In addition, immediately shoreward of the jetty spur head, a void existed on the shoreward side of the spur. The side slopes of the south jetty system were in good condition, with the exception of the jetty head and the jetty spur head as previously discussed.

The most recent walking inspection of the Siuslaw jetties was conducted on 26 August 03. The conditions of the structures were similar to those observed in 1997 with only slight changes. The head of the north jetty appeared to have

flattened slightly since the last inspection with loss of el at the tip (Figure 9). Other voids in the slopes and crests of the north jetty and north jetty spur appeared unchanged. The condition of the south jetty appeared similar to the previous inspection except the head of the south jetty spur appeared to have degraded (unraveled) slightly. The shoreward side of the spur head revealed a void and steep slope (Figure 10). Stones have been displaced and pulled down below the waterline by wave action. With the exception of the problems noted on the heads of the structures, side slopes of the structures were up to design and in good condition.

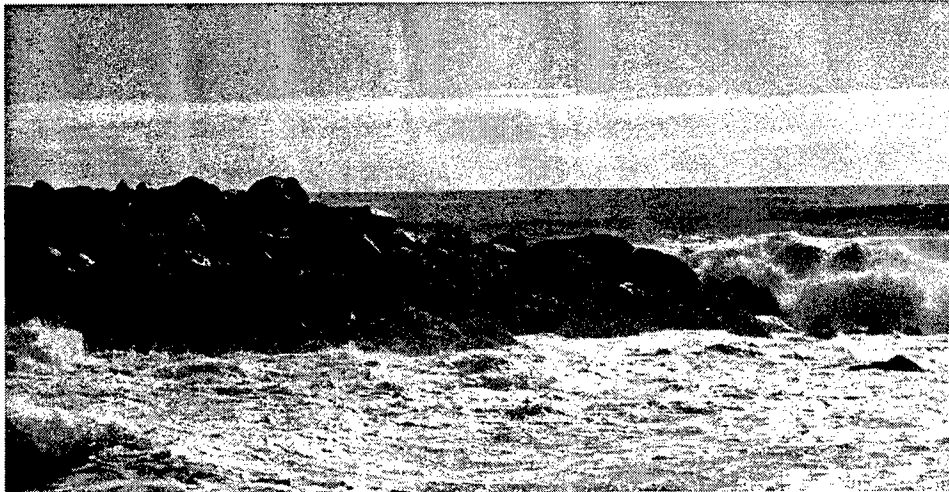


Figure 9. Photo shows loss of elevation at tip of Siuslaw north jetty head



Figure 10. Area on shoreward side of Siuslaw south jetty spur head where steep slope exists

## Umpqua River Training Jetty, OR

The Federal Navigation Project at the Umpqua River lies within the lower 19 km (12 miles) of the Umpqua River estuary. The river entrance is located on the southern Oregon coast approximately 290 km (180 miles) south of the Washington state border and 650 km (405 miles) north of San Francisco Bay, CA. Prior to navigation improvements, the river was connected to the ocean through a 275-m-wide (900-ft-wide) gorge. The first major effort to improve the river entrance for navigation was the construction of a 1,035-m-long (3,390-ft-long) north jetty by local interests during the period 1916-1919. In 1930, the north jetty was extended to its present 2,440-m (8,000-ft) length. A short 762-m-long (2,500-ft-long) south jetty was constructed in 1934 and extended to its present length of 1,280 m (4,200 ft) in 1938. A 7.9-m-deep (26-ft-deep) mllw navigation channel, which extended upstream, also was completed in 1938. The north jetty was rehabilitated during 1941-1942, and a concrete cap was placed on the outer 1,210 m (3,975 ft). This system did not provide a satisfactory entrance due to ebb-tidal currents contributing to deterioration and subsidence of the south jetty. In 1951, a 1,290-m-long (4,240-ft-long) training jetty was constructed generally parallel to the entrance channel, and in 1964 a major rehabilitation of the south jetty was completed. The training jetty was extended 790 m (2,600 ft) in 1980 to the head of the existing south jetty. In general, it paralleled the entrance channel and the north jetty. Design was based on results of a model study (Fisackerly 1970). A layout of the structures is shown in Figure 11. The jetties were of randomly-placed, armor stone construction. The main jetties were armored with 9,070- to 15,420-kg (10- to 17-ton) stone. Armor stone on the channel side of the training jetty averaged 9,070 kg (10 ton) and that on the embayment side averaged 2,720 kg (3 ton).

The training jetty at the mouth of the Umpqua River was monitored during the period May 1983 through May 1984 (Herndon et al. 1992). The objective of the monitoring study was to determine if the training jetty was performing as predicted by physical model studies relative to maintaining the navigation channel.

The training jetty and south jetty were inspected on 25 June 1997. Inspection of the training jetty revealed that the 1980 extension was in very good condition. Its cross section appeared to be uniform along its length, and very few of the armor stone had cracked. The shoreward portion of the structure (1951 construction) had some areas where the shore side of the structure appeared to be damaged. This was prevalent immediately landward of the shoreline where stone from the back side of the jetty was scattered. The channel side face of this portion of the training jetty was in good condition. Inspection of the south jetty revealed a breach at its head. The breach did not extend below the water level, but extended through the jetty. In addition, just shoreward of the breach, a large void existed on the sea side of the structure. The trunk of the south jetty was in good condition.

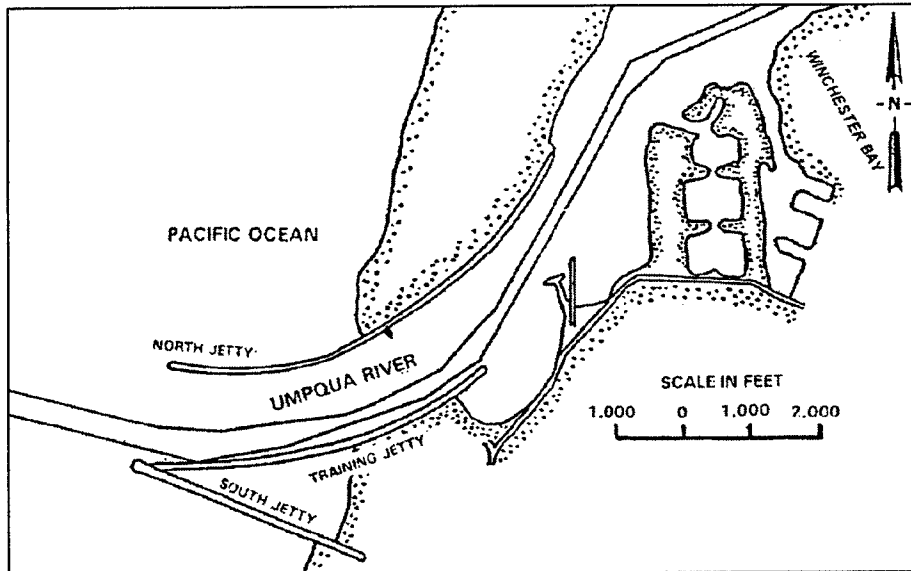


Figure 11. Layout of Umpqua River jetties

The most recent walking inspection of the Umpqua training jetty and south jetty was conducted on 26 August 2003. Observations revealed the conditions of the structures were generally similar to the previous inspection of 1997. A small void was noted, however, where the training jetty tied into the revetment on the landward end. Small voids in the crest as well as slight subsidence in a few areas were also observed along the crest of the training jetty. A view of the training jetty is shown in Figure 12. The breach at the head of the south jetty appeared also to have subsided slightly since it was below the water level (Figure 13). Slight subsidence was also noted in a couple of areas on the crest of the south jetty. The slopes of both structures were in good condition except for the void and breach areas.



Figure 12. View of Umpqua River training jetty (looking shoreward)



Figure 13. Breach at head of Umpqua south jetty

## Crescent City Harbor Breakwater, CA

Crescent City Harbor is located on the northern California coastline, approximately 27 km (17 miles) south of the Oregon border. The existing outer breakwater is 1,423 m (4,670 ft) in length with a 1,118-m-long (3,670-ft-long) main stem and a 305-ft-long (1,000-ft-long) easterly dogleg extension. The original project did not include the dogleg but intended for the main stem to extend to Round Rock (Figure 14). Due to severe damage sustained on the main stem beyond sta 37+00, this option was abandoned and the dogleg previously referred to was added. Original breakwater construction in 1926 consisted of 9,070-kg (10-ton) armor stone. In 1957, the 305-m (1,000-ft) dogleg extension was completed. From sta 36+70 to 41+20, 10,885-kg (12-ton) armor stone was used; and from sta 41+20 to 46+70, 22,680-kg (25-ton) unreinforced tetrapods were placed on the seaward slope. Model tests were conducted to develop design guidance (Hudson and Jackson 1955, 1956). In 1964, the outer breakwater (sta 36+70-41+20) was repaired using 10,885-kg (12-ton) armor stone and 22,680-kg (25-ton) unreinforced tetrapods. In 1974, 36,290-kg (40-ton) unreinforced dolosse were placed on the outer sea-side slope of the breakwater's main stem (sta 34+70 to 37+00). Subsequent storms caused significant amounts of dolosse breakage, and over the years, most of the tetrapods along the elbow of the breakwater had sustained breakage and/or displacement due to large breaking wave conditions. Finally, in 1986, 38,100-kg (42-ton) fiber-reinforced dolosse were placed on the sea-side slope of the main stem and along the elbow of the dogleg (sta 34+00 to 38+05). Design was based on results of a model study (Baumgartner et al. 1985).



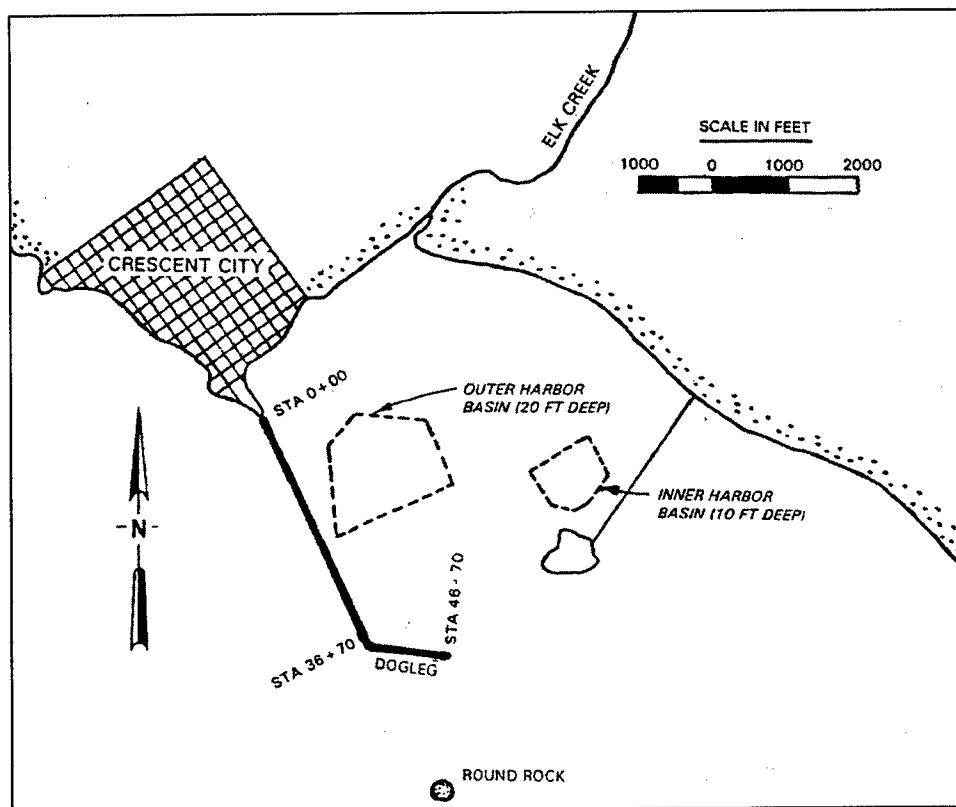


Figure 14. Layout of Crescent City Harbor, CA

The breakwater was monitored between November 1989 and October 1993 as part of the "Periodic Inspections" work unit of the MCNP Program (Markle et al. 1995). The monitoring entailed limited ground surveys, aerial photography, photogrammetric analysis, broken armor unit surveys, and static stress data recording and analysis. Very accurate armor unit positions on the breakwater were obtained during this study.

The Crescent City Harbor breakwater was inspected on 15 September 1998. The inspection indicated that most of the armor unit positions were similar to those shown in the 1993 photography as close as could be observed visually. It appeared that only a couple of the 38,100-kg (42-ton) units had changed positions slightly along the waterline at the outer portion of the main stem.

The breakwater (Figure 15) was again visited on 16 September 2003. The inspection, based on visual observations, revealed the armor units were in similar positions as observed previously. Numerous broken armor units were observed, but most were validated as being broken in previous surveys. Overall the structure was in good condition.



Figure 15. View of Crescent City breakwater

## Humboldt Bay Jetties, CA

Humboldt Bay is located on the northern California coast, about 400 km (260 miles) north of San Francisco. The entrance to the bay is protected by two rubble-mound jetties spaced about 640 m (2,100 ft) apart. The jetties extend seaward from two long narrow sandspits that separate the bay and the ocean. A 152-m-wide (500-ft-wide), 12.2-m-deep (40-ft-deep) mllw entrance channel is maintained between the jetties. The current lengths of the north and south jetties are 2,225 and 2,741 m (7,400 and 8,993 ft), respectively. A layout of the project is shown in Figure 16.

The jetties have experienced a long history of damage and subsequent repairs since construction. Initial jetty construction was completed in 1899 using 7,257-k (8-ton) armor stone. Due to flattening and severe damage, the jetties were capped with 9,071 to 18,144-k (10 to 20-ton) stone in 1911 and concrete monoliths were installed at the heads. Parapet walls were later constructed on the jetty caps. The jetties continued to experience extensive damages, particularly the jetty heads. In 1957, the structure heads were restored with 22,680-k (25-ton) tetrapods and concrete blocks weighing up to 90,718 kg (100 tons). Both jetty heads were totally destroyed in 1969, and in 1971 were reconstructed with 38,100-k (42-ton) dolosse armor units. Design was based on results of a model study (Davidson 1971). The heads have remained relatively stable since the 1971 rehabilitation with no extensive work being required along the dolos fields.

The jetty heads were monitored in 1996 through limited ground surveys, aerial photography, photogrammetric analysis, and a broken armor unit survey as part of the "Periodic Inspections" work unit of the MCNP Program (Bottin and Appleton 1997). Very accurate base level conditions for the dolos armor units were obtained. During the monitoring, 34 broken or cracked dolosse (17 on each jetty head) were identified, and their approximate locations along the structures were documented.

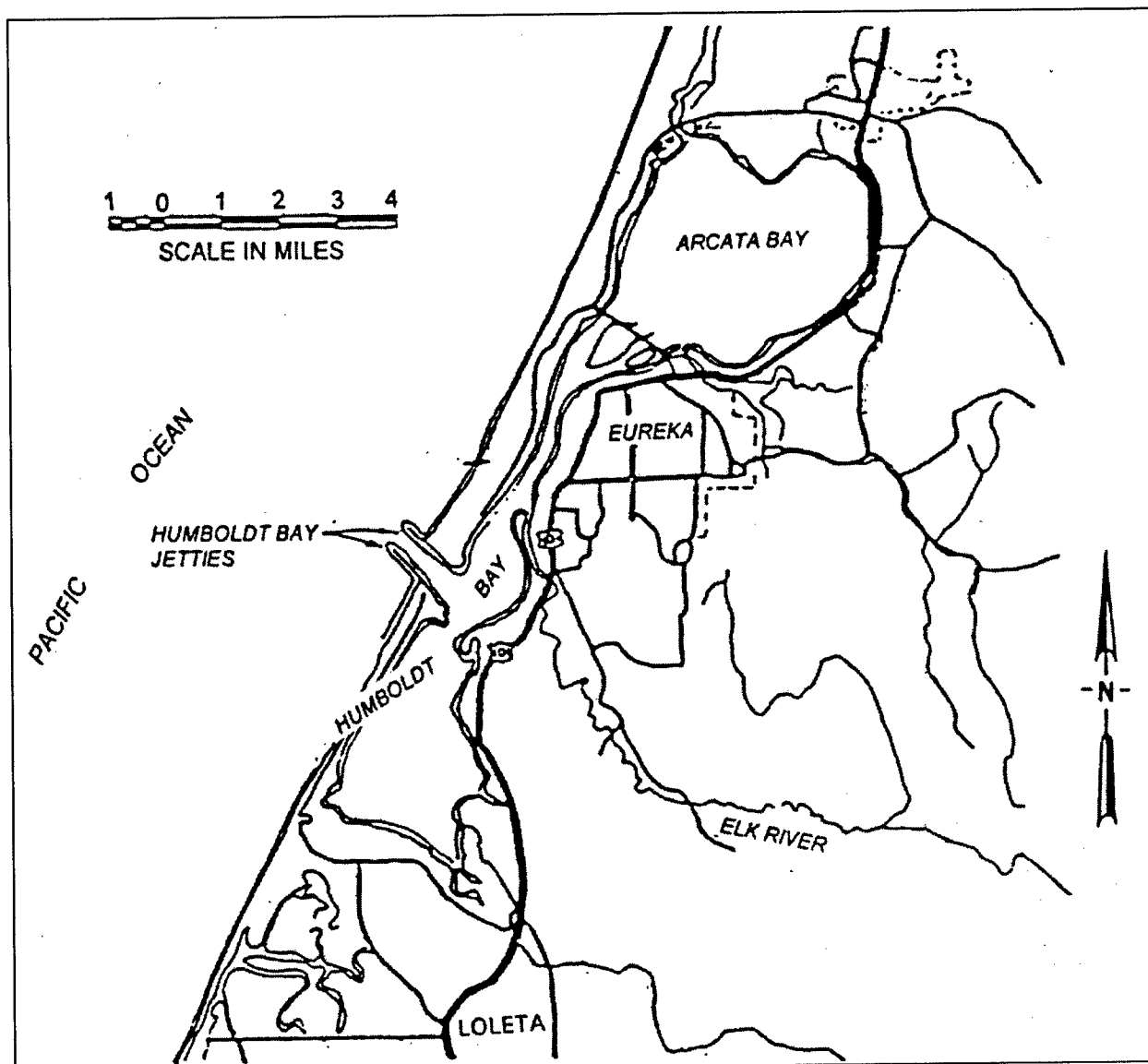


Figure 16. Layout of Humboldt Bay jetties, CA

The heads of the Humboldt Bay jetties were inspected on 17 September 2003. A small void was noted on the seaward quadrant of the north jetty head, and several broken units were observed in this area. Comparisons with previous photography, however, indicated these conditions existed during the 1996 survey. The outer end of the north jetty is shown in Figure 17 and a close-up view of the 38,100-kg (42-ton) dolosse armor cover is shown in Figure 18. Inspection of the south jetty armor units indicated they were in similar positions as in the previous survey. Broken armor units were validated as being broken during the 1996 survey. The jetty heads were functional and in good condition.



Figure 17. Outer end of Humboldt Bay north jetty



Figure 18. Close-up view of 38,100-kg (42-ton) dolosse armor cover

## Burns Harbor Breakwater, IN

Burns Harbor, IN, is located on the southern shoreline of Lake Michigan, approximately 32 km (20 miles) southeast of Chicago, IL. Breakwater construction at the site was completed in 1968, and harbor dredging was completed in 1970. The Burns Harbor structure includes a 1,415-m-long

(4,640-ft-long) rubble-mound north breakwater with an east-west alignment, a 365-m-long (1,200-ft-long) rubble-mound west breakwater with a north-south alignment, and a cellular steel sheet-pile extension connecting the west breakwater to shore. A layout of the harbor is shown in Figure 19.

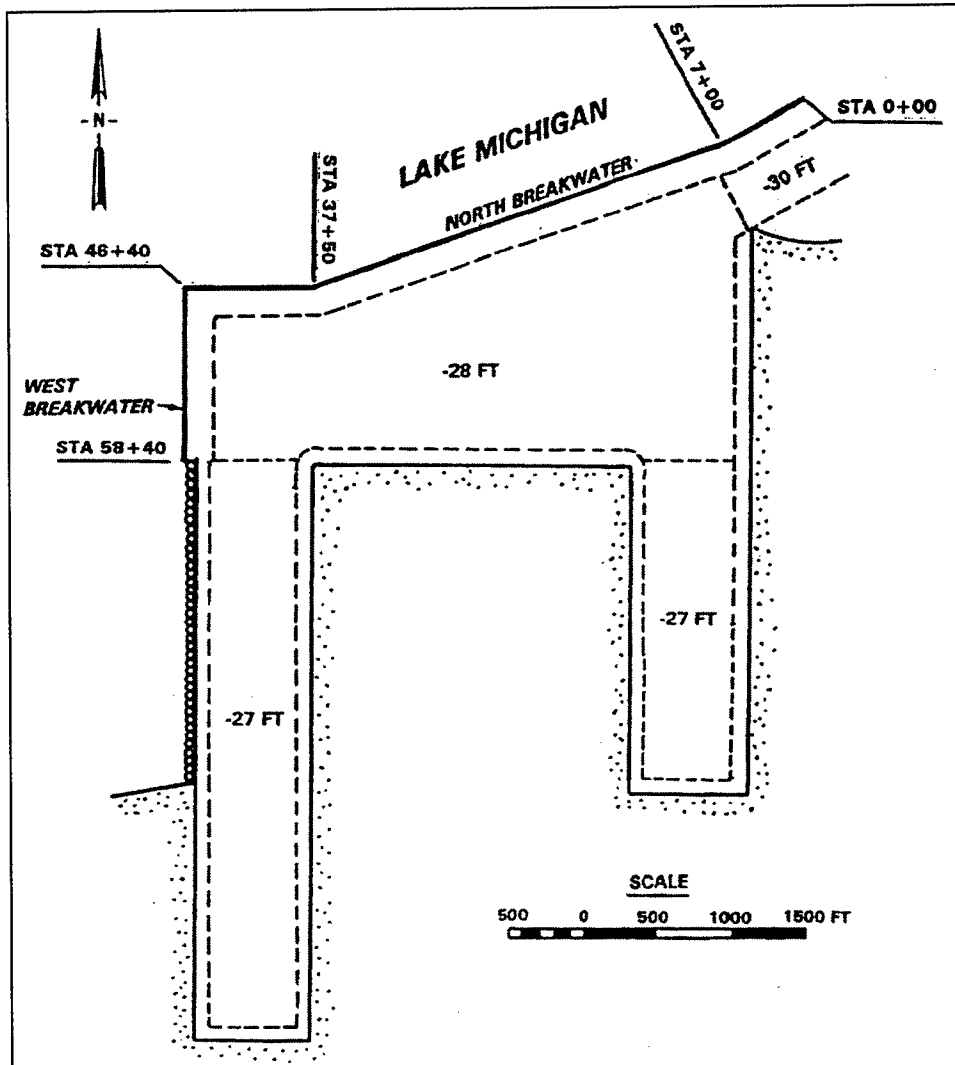


Figure 19. Layout of Burns Harbor, IN

The rubble-mound breakwater was constructed with a multilayered design and random placement of the armor stone cover layer. The crest el was +4.3 m (+14 ft) low water datum (lwd). Armor stones consisted of rectangular cut Indiana Bedford limestone blocks ranging from 9,100 to 13,600 kg (10 to 15 tons) on the trunk and 13,600 to 18,100 kg (15 to 20 tons) on the head. Since completion of construction, extensive breakwater damage has occurred. In the first 19 years of operation, an average of 693,100 kg (7,640 tons) of stone per year had been placed on the breakwater. Between 1975 and 1989, the total amount of maintenance stone placed on the structure was 131,647,900 kg (145,117 tons), representing 54 percent of the entire armor layer stone. The harbor-side and lakeside portions of the breakwater received approximately the

same percentages of stone. Burns Harbor was originally monitored during the period 1985 through 1989, however, detailed, quantifiable positions of the above-water breakwater armor stone were not obtained. The effort studied structural stability, geotechnical stability, and waves and water levels (McGehee et al. 1997). Data collection included site inspections, dive inspections, side-scan sonar surveys, geotechnical data, and wave and water-level data. The north breakwater was monitored under the "Periodic Inspections" work unit of the MCNP Program from November 1994 through July 1995 and consisted of limited ground surveys, aerial photography, photogrammetric analysis, and a broken armor unit survey (Bottin and Matthews 1996). Detailed topography of the above-water portion of the structure was obtained as well as cross sections along the structure at numerous locations. The photogrammetric survey revealed low areas along much of the breakwater. About 24 percent of the total breakwater length was below its design el. In addition, the design width was not maintained in many areas, and the slope on the harbor side of the breakwater was much steeper than the original 1V:1.5H design. The study also revealed a total of 165 broken or cracked armor stones above the waterline. Broken stones occurred along the entire breakwater trunk, however in general, higher concentrations were found along the easternmost portion of the structure. About 50 percent of the broken stones were located on the eastern one-third of the breakwater. No broken armor units were observed around the head.

A walking inspection of the Burns Harbor north breakwater (Figure 20) was conducted on 17 June 1998. The elevation of the breakwater was compared to topography data obtained previously during the photogrammetric analysis. Numerous sections of the structure appeared to have lost el since the previous survey. The inspection also indicated several voids in the breakwater. It appeared that continued deterioration of the breakwater had occurred since the 1994/1995 inspection. It was noted during the inspection, however, that a barge was working lakeward of the north breakwater. Construction of a submerged, offshore reef breakwater was ongoing. The submerged reef was designed to reduce wave heights at the north breakwater during storms, thus resulting in less structure damage as well as decreased wave heights in the harbor. Construction of the reef breakwater was completed in the fall of 1998. Model studies were used to determine reef layout (Acuff and Bottin 1995) and ensure stability (Carver and Wright 1995).

The breakwater (Figure 20) was again monitored in 1999 through limited ground surveys, aerial photography, photogrammetric analysis, and a broken armor unit survey as part of the "Periodic Inspections" work unit of the MCNP Program (Bottin and Tibbetts 2000). Examination of breakwater topography indicated continued loss of structure el as opposed to the 1994/1995 study. Cumulatively, about 46 percent of the total length of the breakwater was below its design el (versus 24 percent previously). As in the previous analysis, the structure crest width was less than its design and steep slopes were observed on the harbor side. A broken armor unit survey revealed 225 broken/cracked armor stones, as opposed to 165 previously. It was noted that most the additional breakage occurred along the harbor-side slope. In 1999, about 44 percent of the broken armor stones were located on the eastern one-third of the breakwater versus 50 percent in the previous study. The 1999 periodic inspection of the breakwater not only determined changes in the armor field since the previous

survey, but established new base conditions since construction of the submerged reef breakwater. Subsequent inspections would evaluate and analyze the performance of the improved project.



Figure 20. View of Burns Harbor breakwater in 1999 (looking east)

Subsequent to the 1999 periodic inspection of the structure, numerous repairs were made to the north breakwater. Between 1999 and 2003, 174,263,923 kg (192,092 tons) of stone were placed on the structure. Repairs to the lakeside were conducted from sta 0+00 to 23+70 and sta 32+50 to 40+65; and repairs on the harbor side occurred from sta 10+50 to 46+30. Repairs involved the placement of stone to flatten the breakwater slopes and raise the crest to design levels. Additional stone placement is scheduled for 2004-2005.

The most recent walking inspection of the Burns Harbor north breakwater (Figure 21) was conducted on 28 April 2004. Several steep areas were noted on the breakwater slopes (Figure 22). Steep slopes were observed on the harbor side of the structure at sta 8+10, 15+00, 16+10, and 17+00; and on the sea side at sta 14+70, 15+00, 25+00, 27+50, 32+30, 37+10-37+50, and 40+80. Most of these areas, however, are in reaches that were not repaired during the 1999-2003 period. A dip in the breakwater crest el was also observed between sta 25+70 and 25+90. Overall, the breakwater was functional and in good condition. Most of the recently repaired reaches were in excellent condition.

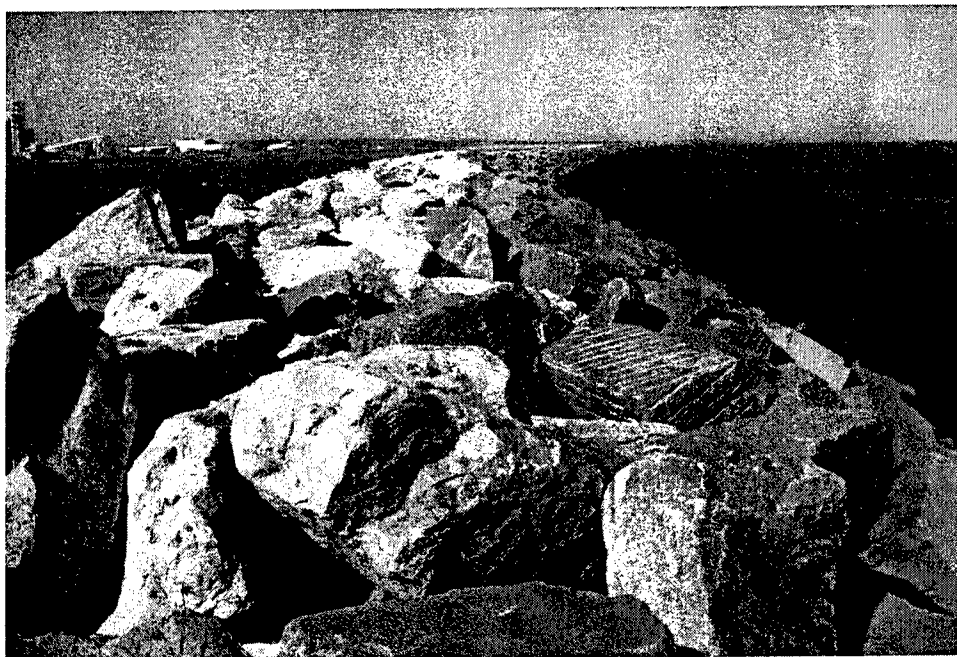


Figure 21. View of Burns Harbor breakwater in 2004 (looking west)



Figure 22. Steep slope on harbor side of Burns Harbor breakwater

## Cleveland Harbor East Breakwater, OH

Cleveland Harbor, OH, is located on the southern shore of Lake Erie, 154 km (96 miles) east of Toledo, OH, and 283 km (176 miles) west of Buffalo, NY. The harbor is situated at the mouth of the Cuyahoga River and comprises approximately 5.3 sq km (1,300 acres). Cleveland Harbor is protected by a



breakwater system, which is over 9,144 m (30,000 ft) in aggregate length. There are two harbor entrances connecting the harbor with Lake Erie. The west entrance is directly lakeward of the Cuyahoga River mouth, and the east entrance is at the eastern end of the east breakwater. A layout of the harbor is shown in Figure 23.

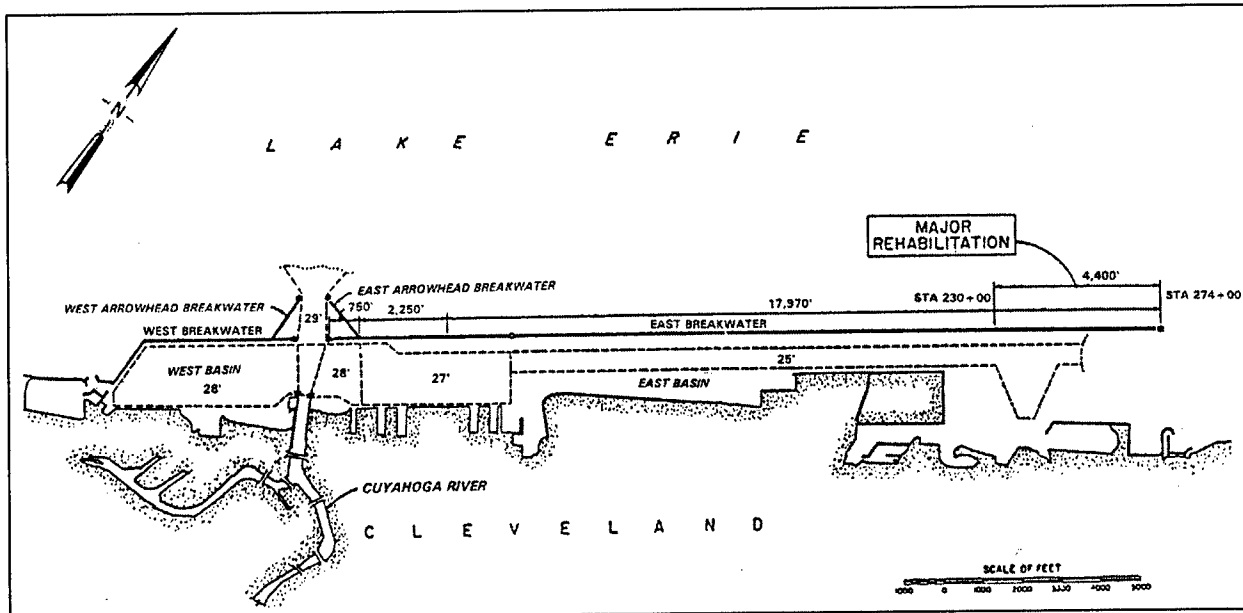


Figure 23. Layout of Cleveland Harbor, OH

The length of the existing east breakwater is 6,392 m (20,970 ft). The westerly 914-m-long (3,000-ft-long) portion was constructed between 1887 and 1900, and was composed of a stone-filled timber crib structure with a concrete cap. During the period 1917-1926, a stone superstructure including a sloping stone armoring, was placed on the lakeward side. The easterly 5,477-m (17,970 ft) portion was constructed between 1903 and 1915 and consisted of dumped core stone covered with large laid-up, individually placed armor stone. The breakwater had a design crest el of +3.14 m (+10.3 ft) lwd and a crest width of 3.05 m (10.0 ft).

The east breakwater has had an extensive repair history. Storm damage has caused the displacement of laid-up cover stone, especially on the lake side, resulting in continuous unravelling of the breakwater slope in many areas. Repairs to the structure, historically, were made by rebuilding the damaged portion in a manner similar to original construction using 2,722- to 7,257-kg (3- to 8-ton) stone. A major rehabilitation project involving the easterly 1,341 m (4,400 ft) of the east breakwater was completed in 1979 (Figure 23). It involved repairing the structure with dolos concrete armor units. The lakeward slope, and in some areas, the crest, were rebuilt using 1,814-kg (2-ton) dolosse placed on a 1V:2H slope on the breakwater trunk. The east head involved a section similar to the trunk, but the slope was constructed on a 1V:2.5H to maintain stability. This was the first use of dolosse on an offshore structure in the Great Lakes environment in the United States.

The rehabilitated dolos section was monitored under the MCNP Program during the period November 1980 through September 1985 (Pope et al. 1993). The monitoring program was to evaluate the magnitude of armor unit breakage, which could compromise the integrity of the structure. It included the collection of aerial photography, wave and water-level data, survey data to determine armor unit movement above the waterline, an inventory of broken dolos units, time lapse photography, and underwater surveys utilizing both side-scan sonar and diver inspections. As evidenced by significant movement and breakage during the monitoring study, the 1,814-kg (2-ton) dolosse appeared to be underdesigned. A total of 692 broken units were observed above the waterline at the conclusion of the study. A model study was conducted to check stability of breakwater rehabilitations (Markle and Dubose 1985). Subsequent to the monitoring, in the spring of 1987, it was noted that most of the dolosse around the head of the eastern end of the structure were missing. The damage was repaired in May 1987 with 3,628-kg (4-ton) dolos armor units as opposed to the 1,814-kg (2-ton) units previously used. Several 3,628-kg (4-ton) dolosse were also placed in low areas along the trunk to bring it back to the correct el. Views of 1,814-kg (2-ton) dolosse along the breakwater trunk and 3,628-kg (4-ton) dolosse on the breakwater head are shown in Figures 24 and 25.

The east breakwater was monitored from July through November 1993 under the "Periodic Inspections" work unit of the MCNP Program. Monitoring consisted of limited ground surveys, low-altitude aerial photography, photogrammetric analysis, and a broken armor unit survey (Bottin et al. 1995). Accurate armor unit positions on the breakwater were obtained as well as detailed topography and point plot maps on the above-water portion of the structure. A total of 782 broken armor units indicated that the rate of breakage on the breakwater had drastically decreased, as opposed to the period after initial construction.

A walking inspection of the Cleveland Harbor east breakwater was conducted on 7 October 1997. The inspection revealed that the structure has changed little since the 1993 survey. Comparison of armor unit positions with detailed, rectified, aerial photography, in general, revealed that most of the armor units were in the same position as in 1993. Even fragments of some broken dolosse were in the same positions based on the aerial photographs. Apparent armor unit movement was observed at only one location along the structure. At sta 262+55 one dolos had moved downslope slightly and an adjacent dolos had flipped upslope. It was also noted that some new 3,628-kg (4-ton) dolosse had been placed between sta 253+50 and 254+00 since 1993.

The most recent walking inspection was conducted on 10 June 2004. In general, it appears the structure has not changed much since the last walking inspection. Most armor units appeared to be in similar positions when compared to the 1993 aerial photographs. There were some areas with isolated changes, however. A void was noted on the lake side of the breakwater at the waterline between sta 230+40 and 230+70 (Figure 26). Other low areas on the lakeside slope were observed at stas 256+60, 257+40 – 257+70, and 260+70. In addition, slight subsidence of the crest was noted between sta 250+30 and 250+50. Some additional 3,628-kg (4-ton) dolosse had been placed on the structure trunk since the 1997 walking inspection. Excessive vegetation (bushes and trees) was also

observed on some portions of the breakwater. The structure was in fair to good condition and appeared to be functioning well.



Figure 24. View of 1,814-kg (2-ton) dolosse along trunk of Cleveland Harbor east breakwater

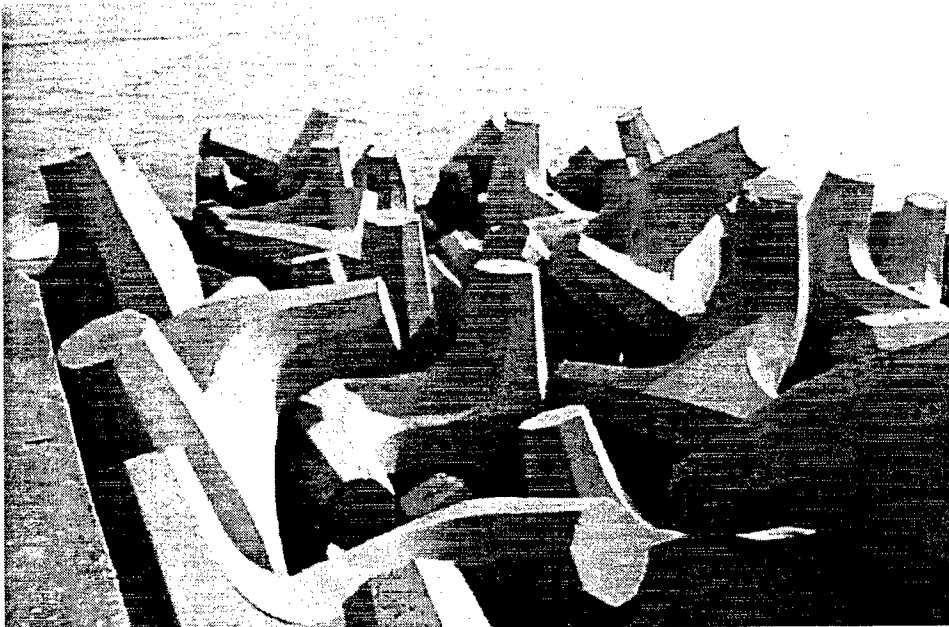


Figure 25. View of 3,628-kg (4-ton) dolosse at head of Cleveland Harbor east breakwater



Figure 26. Void area on lakeside of Cleveland east breakwater between sta 230+40 and 230+70

## Cattaraugus Creek Harbor Breakwater, NY

Cattaraugus Creek Harbor, NY, is located on Lake Erie approximately 38 km (24 miles) southwest of Buffalo, NY, and 87 km (54 miles) northeast of Erie, PA. The project consists of two breakwaters in Lake Erie at the mouth of the creek; a north breakwater 183 m long (600 ft long); a south breakwater 564 m long (1,850 ft long); an entrance channel with an el of -1.7 m (-5.5 ft) lwd; and an interior channel extending upstream about 1,067 m (3,500 ft) with an el of -1.1 m (-3.5 ft) lwd. The breakwaters are of rubble-mound construction, and the south structure has a massive concrete cap that provides a walkway for fishermen. Armor stone for the south breakwater ranges from 1,814 kg to 4,536 kg (2 to 5 tons) at the shore end to 5,443 kg to 11,793 kg (6 to 13 tons) at the head; and for the north breakwater from 1,814 kg to 4,536 kg (2 to 5 tons). Improvements at the site were completed in 1985. A layout of the structures is shown in Figure 27. A model study was conducted to develop the harbor layout (Bottin and Chatham 1975).

The shore-connected breakwaters and channel improvements at Cattaraugus Creek Harbor were monitored between mid-1983 through 1985 under the MCNP Program (Hemsley et al. 1991). An evaluation of waves, structure stability, sediment transport, channel stability, and ice-jam problems due to the construction of the project were studied. At the conclusion of the monitoring it was noted that localized damage had occurred at the south breakwater head. Damage appeared to be due to stone cracking. The loss of shattered stone caused adjacent stone to collapse into voids, resulting in a steepening of the structure slope.

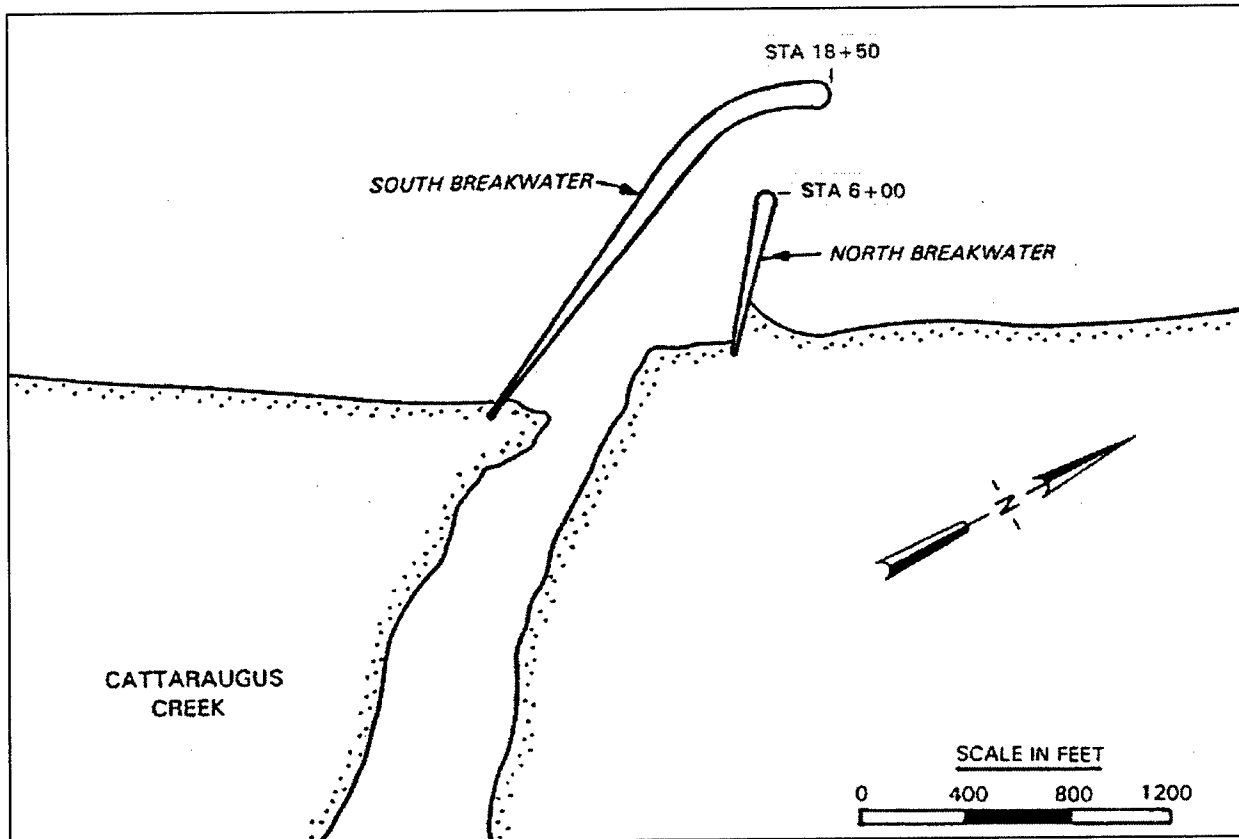


Figure 27. Layout of Cattaraugus Creek Harbor breakwaters, NY

A walking inspection of the Cattaraugus Creek Harbor south breakwater on 8 October 1997 revealed voids in the armor stone layer at two locations on the lake side of the breakwater along the curved portion (sta 15+50 and sta 17+00). An additional void was observed on the head of the structure, which resulted in a steep slope. During the inspection, several broken stones were observed sporadically along the structure; however, overall the structure appeared to be in good condition. The north breakwater was inaccessible and not inspected. It was protected by the curved south structure.

The most recent walking inspection of the Cattaraugus Creek south breakwater (Figure 28) was conducted on 20 May 2004. It was noted that the voids in the breakwater at sta 15+50 and 17+00 appeared similar to photos taken in October 1997. The void at the head, however, had degraded slightly since the previous inspection. Two additional armor stones have been displaced downslope creating a void and steep slope (Figure 29) on the southwest quadrant of the head. As noted earlier, cracked stones were observed sporadically along the structure. Overall the breakwater appeared to be functional and in good condition.

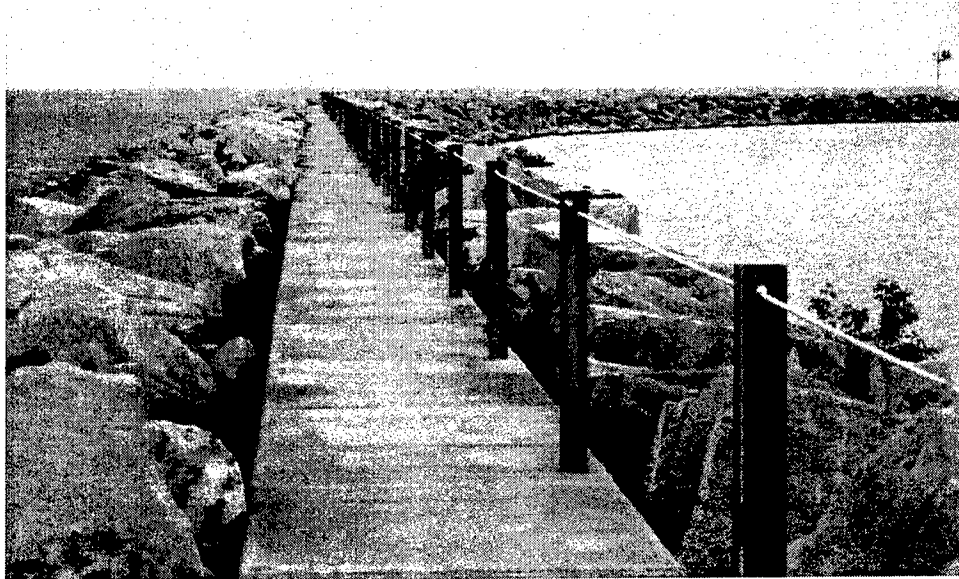


Figure 28. Cattaraugus Creek south breakwater looking lakeward

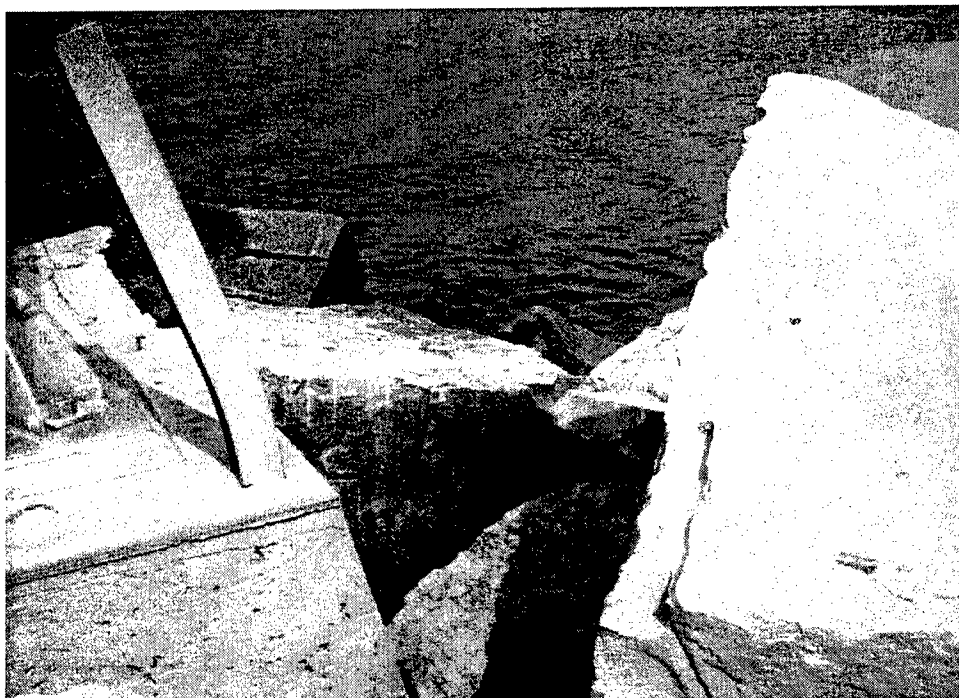


Figure 29. Void and steep slope at head of Cattaraugus Creek south breakwater

## Manasquan Inlet Jetties, NJ

Manasquan Inlet is located on the Atlantic Coast of New Jersey approximately 42 km (26 miles) south of Sandy Hook and 37 km (23 miles) north of Barnegat Inlet. The inlet provides the northernmost connection between the ocean and the New Jersey Intracoastal Waterway. Historical records indicate

the inlet had migrated, and even closed on occasion, prior to jetty construction. Attempts to stabilize the inlet with timber jetties in 1883 and 1922 failed, leading to Congressional authorization of the present project in 1930. The project entailed the construction of two rubble jetties, with steel sheet-pile cores, spaced 122 m (400 ft) apart. The north jetty was 375 m (1,230 ft) long, and the south jetty was 314 m (1,030 ft) in length. Armor consisted of 1,814-kg (2-ton) capstone, and the crest height of the jetties was +4.3 m (+14 ft) mean low water (mlw). A 4.3-m-deep (14-ft-deep) mlw navigation channel was dredged between the jetties. Through the 1970s the jetties were repeatedly damaged by storms and structural settlement. Numerous repairs were attempted, using armor stone of up to 10,890 kg (12 tons), without success. The jetties were rehabilitated in 1982 and involved the use of 14,515-kg (16-ton) dolos armor units. On the south jetty, dolosse were placed on the outer 122 m (400 ft) of the north, or channel side of the structure, around the head, and along the outer 37 m (120 ft) of the structure's south side. On the north jetty, dolosse were placed along the outer 76 m (250 ft) of the structure on its north side, around the head, and along the outer 28 m (90 ft) on the channel side. Inshore of the dolos sections, the slopes were armored with a single layer of 10,890-kg (12-ton) stone. A layout of the jetties is shown in Figure 30.

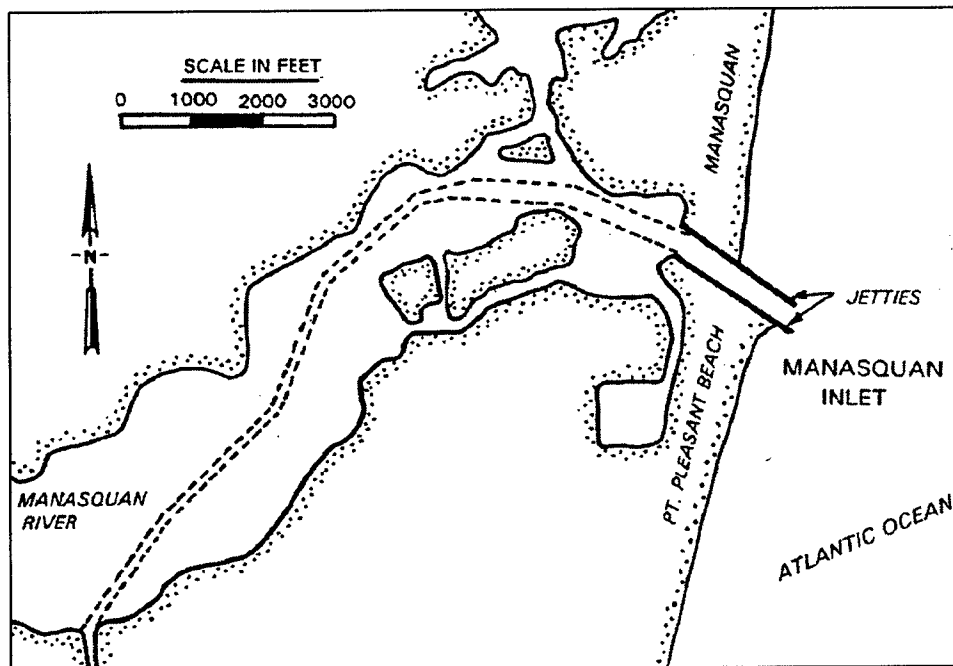


Figure 30. Layout of Manasquan Inlet jetties, NY

The Manasquan Inlet project was monitored during the period June 1982 to October 1984 under the MCNP Program (Gebert and Hemsley 1991). Objectives of the study were to evaluate the performance of the dolos armor units in maintaining structural stability of the jetties, determine potential effects of the rehabilitated jetties on longshore sediment movement at the inlet, and determine the effectiveness of the rehabilitated jetties in maintaining a stable inlet cross section. Data collection included wave measurements, tidal elevation and current

measurements, side-scan sonar surveys, hydrographic surveys, limited ground surveys, aerial photography, and photogrammetric analysis.

The jetties were subsequently monitored under the "Periodic Inspections" work unit of the MCNP Program from August through November 1994 (Bottin and Gebert 1995), and consisted of limited ground surveys, aerial photography, photogrammetric analysis, and a broken armor unit survey. Detailed photomaps of the above-water portion of the structures were obtained. The survey indicated that the dolosse on the north and south jetties had been dynamic since the initial monitoring ended in 1984. Horizontal movement had ranged up to 2 m (6.6 ft) and vertical displacement (subsidence) as much as 1.6 m (5.3 ft). The average movements (both horizontally and vertically), however, were on the order of 0.27 m (0.9 ft) on the north jetty and 0.18 m (0.6 ft) on the south structure. The 1994 broken armor unit survey revealed 17 broken dolosse (as opposed to five in 1984). Of the broken units, nine were located on the north jetty and eight were situated on the south jetty. The monitoring revealed void areas on both jetty heads. On the north jetty, the void area was on the south side of the head. The void area on the south jetty was at its tip, and core stone were exposed in this location. Emergency repair work, consisting of the placement of grout-filled bags, was completed subsequent to the survey on the south jetty as a temporary measure.

A walking inspection of the Manasquan Inlet jetties was conducted on 10 June 1997. Visual comparisons of armor unit positions (to 1994 photomaps) on the north jetty revealed several units had moved slightly. Horizontal movement appeared to range up to 0.6 m (2 ft). In addition, it appeared that minor losses in el had occurred on the downslope portions of some units. Most of these units were adjacent to the void area on the south side of the jetty head, which had been identified in the 1994 survey. The void area also appeared slightly larger than in 1994. Two armor units on the north side of the structure and four on the seaward tip of the jetty also had moved downslope slightly. Most of these movements are likely attributed to a major storm that occurred in 1995. A view of the north jetty head is shown in Figure 31. Inspection of the south jetty revealed that two armor units on the north side of the head had moved slightly shoreward. The area at the head of the south jetty, where the emergency repair work had been completed, appeared to be intact and performed well during the 1995 storm. The storm had washed the lighthouse structure onto the dolosse armor. No additional armor breakage was observed on either jetty during the inspection.

Subsequent to the June 1997 walking inspection, both jetties' void areas were rehabilitated (in October 1997) with 17,235-kg (19-ton) Core-Loc® armor units. Twenty nine Core-Locs were placed on the north jetty and 16 on the south jetty interlocking with the existing dolosse. In addition, nine dolosse were repositioned to improve interlocking and several broken units were removed. Other dolosse were repositioned slightly to provide space for the new Core-Locs to integrate into the overall protection plan. A view of a Core-Loc armor unit is shown in Figure 32.



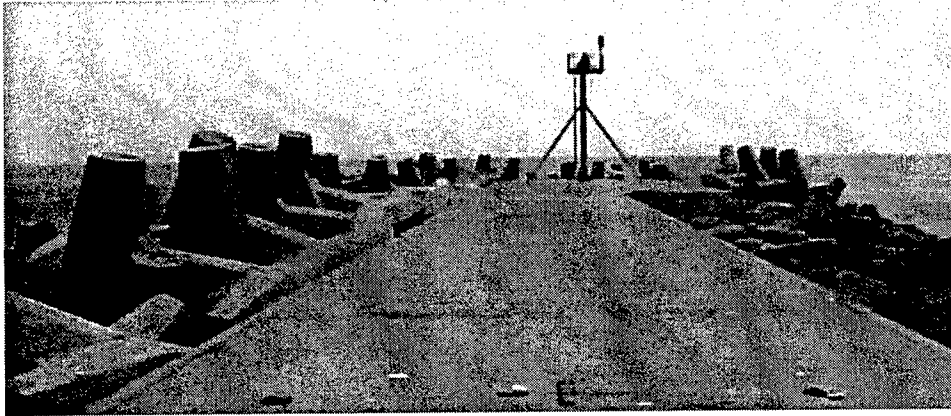


Figure 31. View of Manasquan Inlet north jetty



Figure 32. View of a 17,235-kg (19-ton) Core-Loc armor unit placed on Manasquan Inlet jetties

The Manasquan jetties were again monitored in 1998 through limited ground surveys, aerial photography, photogrammetric analysis, and a broken armor unit survey as part of the “Periodic Inspections” work unit of the MCNP Program (Bottin and Rotherth 1999). Data indicated maximum dolosse movement up to 0.55 m (1.8 ft) in the horizontal direction and vertical displacement up to 0.08 m (0.25 ft) since 1994 on the trunk portions of the jetties. Average movements, however, were more on the order of 0.046 m (0.15 ft) both horizontally and vertically. In the previous surveys, more significant movements had occurred around the jetty heads, but as stated earlier, some dolosse were covered and/or repositioned during the 1997 rehabilitation. During the study, eight broken dolosse were observed (four on each structure). Of the eight broken units, six were identified in the previous 1994 survey, and two were new breaks. Seventeen broken dolosse were observed in 1994. However, several were removed from the heads of the structures in 1997. No broken Core-Locs were observed. The 1998 periodic inspection of the jetties not only determined changes in the dolos armor field since the previous survey, but established new base conditions for the Core-Loc armor units. Subsequent inspections will evaluate and analyze the long-term structural response of the Core-Locs as well.

The most recent walking inspection of the Manasquan Inlet jetties was conducted on 28 May 2003. Armor unit positions were compared to photographs obtained during the photogrammetric survey of 1998. It appeared that insignificant changes had occurred. Armor unit positions appeared to be in the same locations and no additional breakage had occurred. It was noted that many of the dolosse were exhibiting hairline cracks. These may be concrete-curing cracks aggravated by weathering for the last 20-plus years. Spalling may occur at some point in the future. The armor units were structurally and functionally sound, and the structures appeared to be in excellent condition.

## **Ocean City Inlet South Jetty, MD**

Ocean City Inlet, MD, is located about 56 km (35 miles) south of the entrance to Delaware Bay and 170 km (105 miles) north of the Virginia Capes. The inlet was opened in August 1933 by a severe hurricane. Congress subsequently authorized stabilization of the natural inlet. A north jetty was constructed in 1934 to a length of about 335 m (1,100 ft) and an el of +0.8 m (+2.7 ft) mlw. Subsequent rehabilitations resulted in the structure being raised to an el of +3.3 m (+10.7 ft) mlw for the shoreward 30 m (100 ft) and to an el of +2.3 m (+7.7 ft) mlw for the remainder of its length. The south jetty was originally constructed in 1935 with length of about 725 m (2,380 ft). The shoreward section paralleled the north jetty for a distance at which point it angled toward the north jetty, reducing the inlet width. It then paralleled the north jetty again at its seaward end. The crest el of all but the seaward portion was +1.4 m (+4.7 ft) mlw. The el of the outer 110 m (360 ft) of the jetty decreased from +1.4 m (+4.7 ft) to a submerged depth of 1.2 m (4 ft) above the existing bottom.

A new south jetty section was constructed in 1985. It was about 395 m (1,300 ft) in length and offset 9.1 m (30 ft) southerly of the existing jetty center line. The existing jetty was left intact. The new section was constructed with corestone, intermediate stone, one layer of capstone, and precast concrete blocks along the center line (in the trunk) to form a core impermeable to sand transport. The el of the structure was increased to +2.3 m (+7.5 ft) mlw, and capstone ranged from 5,445 to 13,610 kg (6 to 15 tons). The impermeable core wall along the center line consisted of precast, steel-reinforced, concrete blocks with tongue-in-groove interlock joints to maintain alignment and impermeability. The units were 1.8 m (6 ft) wide by 0.6 m (2 ft) long by 1.8 m (6 ft) high. In addition to the south jetty, three headland breakwaters were constructed to stabilize the shoreline adjacent to the shore end of the jetty. These structures were constructed to an el of +1.8 m (+6 ft) mlw with capstones ranging from 2,720 to 4,535 kg (3 to 5 tons). One was 104 m (340 ft) in length and tied into the south jetty, and the other two were each 61 m (200 ft) in length. A layout of the Ocean City Inlet structures after the 1985 rehabilitation is shown in Figure 33.

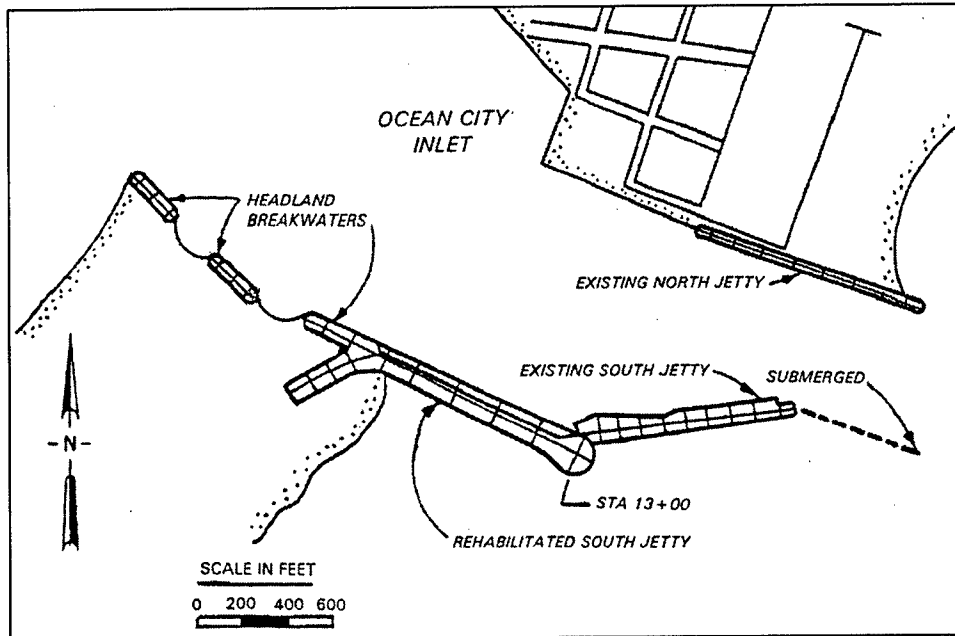


Figure 33. Layout of Ocean City inlet structures, MD, after 1985 rehabilitation

The rehabilitated south jetty at Ocean City Inlet was monitored during the period October 1986 through January 1989 (Bass et al. 1994) as part of the MCNP Program. Activities included beach and offshore surveys, aerial and ground photography of the inlet and adjacent shorelines, inlet hydraulic surveys, nondirectional wave gauging, and side-scan sonar surveys of scour areas.

A walking inspection of the rehabilitated south jetty and headland breakwaters at Ocean City Inlet was conducted on 11 June 1997. The inspection revealed these structures to be in excellent condition. No voids were noted, no armor stones were broken, and the cross sections of the structures appeared to be as-built. It was noted that the seaward section of the old south jetty (that extending beyond sta 13+00) was in disarray. Armor stones were scattered, the crest height was inconsistent, and no definite cross section was apparent. Rehabilitation of the old (pre 1985) south jetty (beyond sta 13+00) was completed in January 2002. Approximately 366 m (1,200 ft) was raised to els of +1.4 m (+4.7 ft) mlw on the trunk and +1.7 m (+5.5 ft) mlw at the head. Armor stone used ranged from 3,630 to 9,070 kg (4 to 10 tons) on the trunk and 8,620 to 14,515 kg (9.5 to 16 tons) on the head.

The most recent walking inspection of the Ocean City Inlet south jetty and headland breakwaters was conducted on 29 May 2003. Armor stone positions were compared to photographs obtained previously in 1997. The rehabilitated south jetty (to sta 13+00, Figure 34) and the three headland breakwaters (Figure 35) appeared to be in excellent condition. No voids were noted, no broken armor stones observed, and the cross sections again appeared to be as-built. It was noted that slight spalling of the precast concrete core was occurring (probably due to weathering), but the structure was structurally and functionally sound. The recently rehabilitated outer portion of the south jetty (beyond sta 13+00) also appeared to be in excellent condition (Figure 36).



Figure 34. View of inner portion (to sta 13+00) of rehabilitated Ocean City inlet south jetty trunk



Figure 35. Headland breakwaters at Ocean City inlet constructed to stabilize shoreline



Figure 36. Seaward portion of south jetty at Ocean City inlet (beyond sta 13+00) after 2002 rehabilitation

### 3 Summary and Recommendations

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Inspections of rubble-mound coastal structures that had previously been monitored under the MCNP Program at 11 sites were completed from May 2003 through June 2004. These were expedient, low-cost assessments that consisted of walking inspections and/or boat surveys. Comparisons of changes in the structures since they were last surveyed were noted. Summaries of the results as well as recommendations are presented as follows:

- a. Inspection of the St. Paul Harbor main breakwater, AK, revealed subsidence and voids in isolated areas of the structure. When compared to the previous survey data of 2000, however, little change was noted in breakwater elevation. Further deterioration of some of the broken/cracked armor stones previously identified was observed. Overall, the breakwater was in good condition. It should be inspected annually due to the extreme wave and ice climate to which it is subjected.
- b. Inspection of the Yaquina Bay north jetty, OR, revealed some low areas in the crest and some voids on the slopes of the jetty. These observations were also noted in the previous inspection of 1997. The head of the structure, rehabilitated in 2001, was in excellent condition. Consideration should be given to placing armor stones in the voids of the structure trunk during scheduled maintenance to prevent future major damage, and in areas along the structure crest to bring the jetty back to its design cross section. The trunk of the jetty is in good condition overall. The structure should be inspected periodically, particularly after major storm events.
- c. Inspection of the Siuslaw River jetties, OR, indicated that only slight changes had occurred since the previous inspection in 1997. Voids at two locations on the channel side of the north jetty were observed as well as low areas in the center of the jetty crest. The north jetty head had lost elevation since the previous inspection. Damage on the head of the south jetty was observed as evidenced by a lack of stone above the water surface and a very steep slope. The south jetty spur head had degraded slightly since the last inspection. The shoreward side of the spur head had an extremely steep slope where stones had been displaced and pulled downslope below the waterline. The structures' slopes were in good condition except in the void areas. Consideration should be given to

placing armor stones in the voids and damaged areas identified on the jetties and jetty spur during scheduled maintenance to prevent further damage in the event of a major storm. Consideration should also be given to placing armor stones in areas along the structure's crest to bring it back to its design cross section. The jetties should be inspected periodically, particularly after major storm events.

- d. Inspection of the Umpqua River training jetty, OR, indicated it was generally in very good condition with only slight changes since the previous inspection of 1997. At the shoreward end of the training structure, it was noted that some stone from the jetty was scattered on the shore. There was also a small void where the jetty tied into the revetment on the landward side, and a few areas of slight subsidence along the crest. Inspection of the south jetty indicated a breach at its head and a large void on the sea side of the structure just shoreward of the breach. The breach did not extend below the water surface in 1997; however, in 2003 it had subsided to below the water. The trunk of the south jetty was generally in good condition with only a couple of areas on the crest revealing slight subsidence. Consideration should be given to repairing the breach and void at the head of the south jetty with armor stones during scheduled maintenance to prevent further damage, and potential failure, of the structure in the event of a major storm. The breakwater system then should be inspected periodically, especially after major storm events.
- e. Inspection of the Crescent City Harbor breakwater, CA, indicated that most of the armor unit positions were similar to those of the previous survey of 1993. Based on visual observations, only a few units had slightly changed positions along the waterline on the sea side of the outer portion of the main stem. Broken armor units were observed, but most were validated as being broken during previous surveys. Overall the structure was in good condition. The breakwater should be inspected periodically, particularly after major storm events. It has been 10 years since the structure was formally monitored under the MCNP Program. A photogrammetric survey should again be conducted to quantify armor unit movements and analyze the armor cover layer over this time frame.
- f. Inspection of the Humboldt Bay jetties, CA, revealed a small void with several broken dolos on the seaward quadrant of the north jetty head; however, these conditions existed during a survey conducted in 1996. In general, the armor unit positions on the jetty heads were in similar positions as the previous survey. The jetty heads were functional, appeared to be stable, and were in good condition. They should be inspected periodically, particularly after storm events.
- g. Inspection of the Burns Harbor breakwater, IN, revealed that the structure's cross section was significantly improved as opposed to the previous inspection in 1999. Repairs to various reaches of the breakwater were performed between 1999 and 2003 to flatten slopes and raise the crest to design levels. Several steep areas were noted during the inspection on the sea side and harbor sides of the breakwater as well as

an area of crest subsidence. However, most deficiencies were in reaches that were not recently repaired. Additional stone placement is scheduled during 2004-2005. Overall, the breakwater was in good condition, and recently repaired portions were in excellent condition. The structure should be inspected periodically, particularly after major storm events. After repairs are completed in 2005, consideration should be given to formally monitoring the structure through photogrammetry to establish new base conditions upon which to evaluate the performance of the rehabilitated breakwater.

- h.* Inspection of the Cleveland Harbor east breakwater, OH, indicated overall that the structure armor unit (dolosse) positions had not changed significantly since the previous inspection. Several voids and low areas were noted, however, on the sea side of the breakwater slope as well as an area of subsidence on the crest. Excessive vegetation also was noted on some areas of the structure, and numerous broken armor units were observed, most of which were noted as broken during the previous surveys. The structure was in fair to good condition and appeared to be functioning well. Consideration should be given to placing additional armor units in the voids and low areas during scheduled maintenance and to removing the overgrown vegetation. The breakwater should be inspected periodically, particularly after storm events. It has been 11 years since the structure was formally monitored under the MCNP Program. A photogrammetric survey should again be conducted to quantify armor unit movement and analyze the armor cover layer over this time frame.
- i.* Inspection of the Cattaraugus Creek Harbor south breakwater, NY, indicated voids in the armor stone layer at two locations along the lake side of the structure trunk and a void at the head of the breakwater, all which resulted in steep slopes. Comparison of armor stone positions with the previous inspection of 1997 indicated a slight degradation at the head where two additional stones on the southwest quadrant had been displaced downslope resulting in a void and steep slope. Broken armor stones were observed sporadically along the structure; however, overall the structure appeared to be in good condition. Consideration should be given to placing armor stones in the voids identified during scheduled maintenance to prevent additional damage. The structure should be inspected periodically, particularly after storm wave events.
- j.* Inspection of the Manasquan Inlet jetties, NJ, revealed the structures to be in excellent condition. Voids identified on the heads of both the north and south jetties in the previous 1997 inspection had been subsequently repaired with Core-Loc armor units. Insignificant changes had occurred in the positions of dolos along the trunks of the jetties when compared to the previous 1997 inspection, nor was additional armor unit breakage observed. Hairline cracks were noted on some dolos; however, the structures were functionally and structurally sound. They should be inspected after major storm events.



- k. Inspection of the Ocean City Inlet south jetty and headland breakwater, MD, indicated the structure to be in excellent condition. No voids were noted, no armor stones were broken, and the jetty cross section appeared to be as-built. The structure should be inspected after major storm events.

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) September 2004		2. REPORT TYPE Final report		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE  Inspections of Previously Monitored Rubble-Mound Coastal Structures				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)  Robert R. Bottin, Jr., Larry R. Tolliver, Glenn B. Myrick				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Coastal and Hydraulics Laboratory U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road, Vicksburg, MS 39180-6199				8. PERFORMING ORGANIZATION REPORT NUMBER  ERDC/CHL TR-04-11	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)  U.S. Army Corps of Engineers Washington, DC 20314-1000				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT This report presents results of inspections of rubble-mound coastal structures monitored previously under the Monitoring Completed Navigation Projects (MCNP) Program. Expedient, low-cost walking inspections were performed at 11 sites. Positions of breakwater and jetty armor units were compared with their positions in previous aerial photography and photogrammetric surveys. Settlement of portions of the structures as well as voids in their armor cover also was noted, and photographs of the structures were obtained. Summaries of inspection results as well as recommendations are presented in this report. The work was conducted under the "Periodic Inspections" work unit of the MCNP Program.					
15. SUBJECT TERMS Armor units Breakwaters		Coastal structure inspections Core-Locs Dolosse		Jetties	
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES  55	19a. NAME OF RESPONSIBLE PERSON
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (include area code)